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Articles

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ATINER is a ***World Non-Profit Association*** of Academics and Researchers based in Athens. ATINER is an independent **Association** with a **Mission** to become a forum where Academics and Researchers from all over the world can meet in Athens, exchange ideas on their research and discuss future developments in their disciplines, **as well as engage with professionals from other fields**. Athens was chosen because of its long history of academic gatherings, which go back thousands of years to *Plato's Academy* and *Aristotle's Lyceum.* Both these historic places are within walking distance from ATINER's downtown offices. Since antiquity, Athens was an open city. In the words of Pericles, **Athens*"…is open to the world, we never expel a foreigner from learning or seeing".*** ("Pericles' Funeral Oration", in Thucydides, *The History of the Peloponnesian War).* It is ATINER's **mission** to revive the glory of Ancient Athens by inviting the World Academic Community to the city, to learn from each other in an environment of freedom and respect for other people's opinions and beliefs. After all, the free expression of one's opinion formed the basis for the development of democracy, and Athens was its cradle. As it turned out, the Golden Age of Athens was in fact, the Golden Age of the Western Civilization. *Education* and *(Re)searching* for the 'truth' are the pillars of any free (democratic) society. This is the reason why *Education* and *Research* are the two core words in ATINER's name.

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Before you submit, please make sure your paper meets some basic academic standards, which include proper English. Some articles will be selected from the numerous papers that have been presented at the various annual international academic conferences organized by the different divisions and units of the Athens Institute for Education and Research.

The plethora of papers presented every year will enable the editorial board of each journal to select the best ones, and in so doing, to produce a quality academic journal. In addition to papers presented, ATINER encourages the independent submission of papers to be evaluated for publication.

The current issue of the Athens Journal of Technology & Engineering (AJTE) is the third issue of the sixth volume (2019). The reader will notice some changes compared with the previous volumes, which I hope is an improvement. An effort has been made to include papers which extent to different fields of Technology and Engineering.

Gregory T. Papanikos, President
Athens Institute for Education and Research

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10th Annual International Conference on Civil Engineering
20-25 June 2020, Athens, Greece

The Civil Engineering Unit of ATINER is organizing its **10th Annual International Conference on Civil Engineering, 22-25 June 2020, Athens, Greece** sponsored by the Athens Journal of Technology & Engineering. The aim of the conference is to bring together academics and researchers of all areas of Civil Engineering other related areas. You may participate as stream leader, presenter of one paper, chair of a session or observer. Please submit a proposal using the form available (https://www.atiner.gr/2020/FORM-CIV.doc).

Academic Members Responsible for the Conference

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Important Dates

- Abstract Submission: **18 November 2019**
- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **25 May 2020**

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Athens Institute for Education and Research

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The Industrial Engineering Unit of ATINER will hold its **8th Annual International Conference on Industrial, Systems and Design Engineering, 22-25 June 2020, Athens, Greece** sponsored by the Athens Journal of Technology & Engineering.The aim of the conference is to bring together academics, researchers and professionals in areas of Industrial, Systems, Design Engineering and related subjects. You may participate as stream leader, presenter of one paper, chair of a session or observer. Please submit a proposal using the form available (https://www.atiner.gr/2020/FORM-IND.doc).

Important Dates

- Abstract Submission: **18 November 2019**
- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **25 May 2020**

Academic Member Responsible for the Conference

- **Dr. Theodore Trafalis**, Director, Engineering & Architecture Division, ATINER, Professor of Industrial & Systems Engineering and Director, Optimization & Intelligent Systems Laboratory, The University of Oklahoma, USA.

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High Strength Concrete Tests under Elevated Temperature

By Zhuoya Wu, Sai Huen Lo†, Kang Hai Tan‡ &*
Kai Leung Su♦

In recent years, application of high strength concrete (HSC) has attracted increasing interest in the construction industry due to its significant economic, architectural, and structural advantages, compared to the conventional normal strength concrete (NSC). However, under fire condition, which is one of the most common hazards that attack building structures, HSC members may be subjected to explosive spalling. Strength reduction of structural members may occur, leading to severe consequences such as failure of members or even collapse of the whole structure. A newly designed 2-layered cylindrical specimen consisting of an HSC core and an NSC outer layer is proposed to improve the fire performance of HSC members under elevated temperature. The NSC layer is designed to act as an outer layer insulation to reduce the thermal gradient and also serve as a lateral confinement to prevent the HSC core from spalling. Compression and thermal tests were performed on the specimens to investigate their strength and behavior under elevated temperature. Test results preliminarily verify the feasibility of 2-layered design and at the same time provide insights for the applicability of 2-layered columns in practical construction projects.

Keywords: *2-Layered Specimens, Elevated Temperature, High Strength Concrete, Normal Strength Concrete, Spalling.*

Introduction

High strength concrete (HSC), as one of the most widely used construction materials, gains increasing popularity in the recent years due to the upsurge of high-rise buildings, long-span bridges and tunnels. Compared to the normal strength concrete (NSC), HSC has advantages in not only the structural but also the economic and aesthetic aspects. When applied in buildings, HSC is commonly used as structural members such as beams, columns and slabs, which function as the load bearing elements. It is therefore of particular importance to make sure that the high strength concrete members could survive from those extreme environmental conditions, among which fire has aroused primary concerns due to the spalling of HSC when exposed to elevated temperatures. Spalling refers to the breaking away of surface layers (pieces) of concrete from the structural elements exposed to high and rapidly rising temperatures, and the explosive spalling occurs in a more sudden and violent manner (Kodur 2000, Phan 2008). Though there is no one mechanism that can fully interpret this phenomenon, it

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is believed by the majority that due to the high compactness (low porosity) of HSC, water vapor pressure trapped inside the concrete could induce spalling when the pore pressure gradually builds up and exceeds the tensile strength of concrete under elevated temperatures (Dwaikat and Kodur 2009, Phan 2002, Kodur et al. 2004, Ichikawa and England 2004, Ozawa et al. 2012, Kalifa et al. 2000, Mindeguia et al. 2010b).

Considering the fact that spalling usually occurs in depth of 10-50mm from the concrete surface (Jeongwon et al. 2011), this study presents a newly designed 2-layered (2L) cylindrical specimen consisting of an HSC core and an NSC outer layer to mitigate the effect of spalling. The NSC layer is designed to act as an outer layer insulation to reduce the thermal gradient and also as a lateral confinement to prevent the HSC core from spalling. Although fiber-reinforced HSC is one of the most commonly used method to mitigate spalling, drawbacks still exist. For concrete reinforced with polypropylene (PP) fiber, elastic modulus and compressive strength of the concrete are reduced (Wang et al. 2019, Jalasutram et al. 2017). For concrete reinforced with steel fiber, Zheng et al. (2018) pointed out the traditional mixing method could lead to the non-uniform distribution of steel fiber, mechanical properties of the concrete would therefore be affected. Chaichannawatik et al. (2018) found that the addition of fibers in the concrete would reduce the workability of the fiber-reinforced concrete. On account of the lower workability, reduced compressive strength and difficulty of uniform mixing on site, it is necessary to implement the proposed 2-layered design.

Literature Review

Studies on the effects of high temperature on the mechanical properties of HSC could trace back to as early as the 1980s. Among these early studies were mostly material tests (Felicetti et al. 1996, Furumura et al. 1995, Sullivan and Sharshar 1992, Hammer 1995, Diederichs et al. 1988, Hertz 1992, Hertz 1984, Castillo and Durrani 1990) and element tests (Diederichs et al. 1995, Hansen and Jensen 1995, Sanjayan and Stocks 1993, Shirley et al. 1988). There were also some other early studies that adopted different techniques, for instance, the scanning electron microscopy and stiffness damage test to evaluate the properties and behavior of HSC at elevated temperatures (Lin et al. 1996, Nassif et al. 1995).

Castillo and Durrani (1990) investigated the compressive strength and load-deformation relationship of HSC exposed to high temperature by conducting stressed and unstressed tests on cylinders made of high strength and normal strength concrete mixtures. Hertz (1984) and Hertz (1992) examined the effect of temperature, cylinder size and dosage of steel fibers on the compressive strength, elastic modulus and explosion behavior of silica-fume HSC and lightweight concrete. Diederichs et al. (1988) studied the material properties as well as the specimen shape and heating rate by performing unstressed tests, transient creep and relaxation tests on the specimens of three HSC with different mineral additions (blast furnace slag, silica fume and fly ash). Hammer (1995) observed a typical “breakpoint” at around 300℃ in the strength-temperature curves, where an explosive failure may occur followed by the release of steam. Sullivan and Sharshar (1992) concluded that aggregate type could significantly affect the residual strength of concrete subjected to high temperature. Furumura et al. (1995) noted that in the unstressed tests there was a compressive strength recovery to ambient strength at 200℃, which is not observed in the unstressed residual strength tests. Felicetti et al. (1996) performed unstressed residual strength tests on the HSC cylinder specimens and the test results revealed similar trends of reductions in compressive strength and elastic modulus as observed in other experimental studies mentioned above. Noumowe et al. (1996) conducted unstressed residual tests on NSC and HSC specimen. Results showed that both tensile strengths decreased similarly and almost linearly with increasing temperatures and NSC would become more porous than HSC as temperatures increased beyond 120℃.

Three series of reinforced and prestressed concrete beam tests were performed in the research of Hansen and Jensen (1995), which showed that beams with fibers and protective coating were less suspected to spalling. Observations from the full scale T-beams fire tests by Sanjayan and Stocks (1993) reported HSC possesses a higher possibility of spalling in a fire than NSC and the drying rate of HSC is slower than NSC indicated by its higher moisture content. The report by Diederichs et al. (1995) summarized results from three column tests and indicated that the use of fibers to form capillary can help reduce the risk of spalling in HSC columns and also suggested that further researches may study the effects of various fiber contents. Shirley et al. (1988) conducted fire tests on HSC slab and concluded that the fire endurance of HSC and NSC had no significant difference and none of the specimens experienced any spalling or explosive behavior.

The one problem that early studies commonly address is the spalling or explosive behavior of HSC at elevated temperatures, though inconsistencies are also observed from the test results. While some researchers reported spalling phenomenon in HSC structural members, there were a few experimental studies showing little or no obvious spalling. Possible reason for this conflicting picture on the occurrence of spalling may attribute to the massive number of factors that affect spalling and their interdependency. To better understand the behavior and mechanism of HSC under elevated temperature, and to satisfy the fire safety requirements in practical construction projects, more recent researches has been done regarding the fire resistance of HSC.

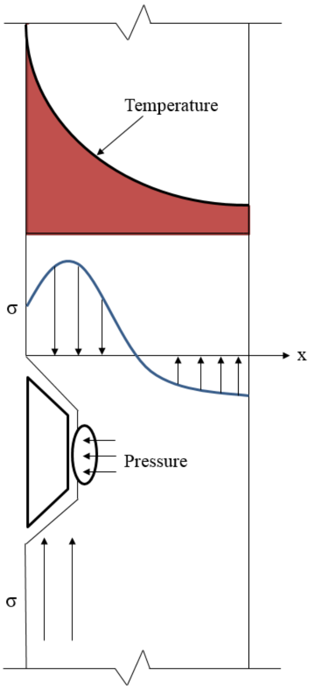
Mechanisms of Spalling

The spalling pattern of HSC could be classified as minor, moderate and severe (explosive), according to the extent of spalled concrete. Spalling refers to the breaking away of surface layers (pieces) of concrete from the structural elements exposed to high and rapidly rising temperature, and the explosive spalling occurs in a more sudden and violent manner (Phan 2008, Kalifa et al. 2000, Phan and Carino 2002, Kodur 2000). In cases of severe spalling, it is very likely that the reinforcement would be directly exposed to heat, and therefore loss of load bearing capacity of structural members may occur, leading to severe consequences such as failure of members or even collapse of the whole structure. A review of literature shows that there are mainly three mechanisms that could account for the spalling phenomenon of HSC (Kodur 2000, Kodur et al. 2004, Jeongwon et al. 2011, Ozawa et al. 2012, Phan 2002).

Thermal-Mechanical Spalling

When concrete is heated under fire, thermal stress develops due to restrained thermal expansion. When tensile stress reaches some critical values, vertical cracks will form between the concrete core and concrete cover (Gawin et al. 2003). If a driving force, such as axial compression, bending stress, or thermal expansion of concrete is applied, thermal-mechanical spalling happens. According to the studies conducted from the aspect of thermal stress, the critical factor influencing the thermal expansion is coarse aggregate (Jeongwon et al. 2011), and the presence of carbonate aggregate could help improve the fire endurance of HSC other than the siliceous aggregate (Kodur et al. 2003). In general, thermal-mechanical spalling occurs when the compressive strength of concrete is exceeded at the cover. A schematic diagram of thermal-mechanical spalling of a concrete column is depicted in Figure 1.

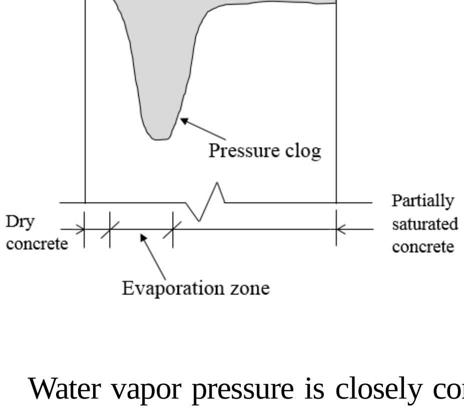
Figure 1. *Schematic Diagram of Thermal-Mechanical Spalling (Kodur 2000)*



Thermal-Hydro Spalling

High strength concrete is made by lowering the water/cement ratio and adding some ultra-fine materials such as silica fume that can increases the strength of the cement-aggregate bond. Superplasticizers are also commonly added to the high strength mixes in order to compensate for the reduced workability. When concrete is heated under elevated temperature, liquid water inside the concrete will become vapor. Due to the low permeability (compact) nature of HSC, the vapor cannot escape the concrete, leading to the gradual build-up of pore pressure around the concrete surface. At 300°C, the pore pressure could approximately reach 8MPa (Kodur 2000, Kodur et al. 2004). The tensile strength of concrete is much lower than its compressive strength, when concrete could not resist the induced pore pressure, spalling occurs. At the time of spalling, the pore pressure roughly equals to the saturated vapor pressure (SVP) (Mindeguia et al. 2010a, Kalifa et al. 2000). A schematic diagram of thermal-hydro spalling of a concrete column is depicted in Figure 2. It is reported by Hertz (2003) that low water content by weight (3-4% or less) could reduce the possibility of spalling in concrete, a phenomenon that cannot be solely explained by the thermal-mechanical spalling theory, and is deemed to be mainly affected by the water vapor pressure (pore pressure). Thermal-hydro spalling, occurring at early stage of heating and with fierce spalling process, is therefore considered as the most critical spalling by the majority of researches, though it is still difficult to conclude an exact mechanism to fully interpret the phenomenon of fire induced spalling in HSC based on the state-of-the art (Khaliq and Kodur 2011, Khaliq and Kodur 2013, Phan and Carino 1998, Phan and Carino 2002, Jeongwon et al. 2011, Ozawa et al. 2012).

Figure 2. *Schematic Diagram of Thermal-Hydro Spalling (Kodur 2000)*

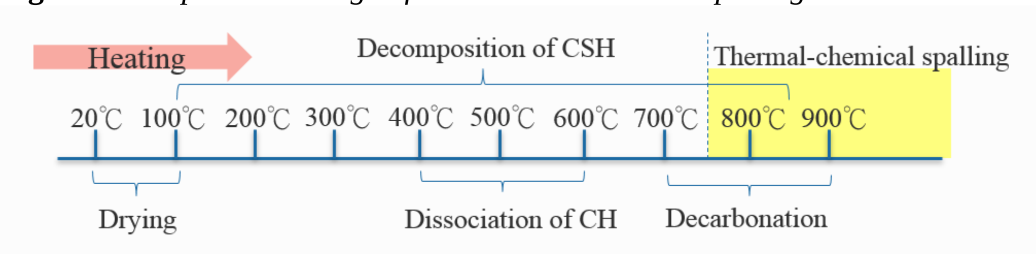


Water vapor pressure is closely connected to the heat or moisture transfer in concrete, which is strongly affected by the moisture conditions with concrete, and the effect is particularly strong in a high-temperature environment (Jeongwon et al. 2011). Measurement of heat/moisture transfer and pressure build-up is of great difficulties due to the restricted test conditions and the nature of the measured experimental process. However, development of new experimental methods accompanied by the progress in the test apparatus has promoted a few experimental and analytical studies on heat conduction, moisture transfer and pore pressure build-up (Kalifa et al. 2000, Zdeněk and Werapol 1979, Bažant et al. 1982, Ahmed and Hurst 1999, Phan 2008, Ichikawa and England 2004, Dwaikat and Kodur 2009, Phan 2002), though most of the pore pressures investigated are in one direction only. The experimental studies pay special attention to the data from the proximity of concrete surfaces reasoning the fact that spalling take place primarily in the range of 10-50mm depth from surface (Jeongwon et al. 2011).

Thermal-Chemical Spalling

Thermal chemical spalling consists of two types of spalling, namely, sloughing-off spalling at extremely high temperature and post cooling spalling after exposing to elevated temperature (Xing et al. 2011). The main cause of thermal-chemical spalling is the break-down of aggregate cement bond, such as calcium silicate hydroxide and calcium hydroxide (Schneider 1988). Since the threshold temperature of thermal-chemical spalling is relatively high at around 750℃, it is considered to be the least critical among the three mentioned spalling. The temperature of thermal-chemical spalling is shown in Figure 3.

Figure 3. *Temperature Range of Thermal-Mechanical Spalling*

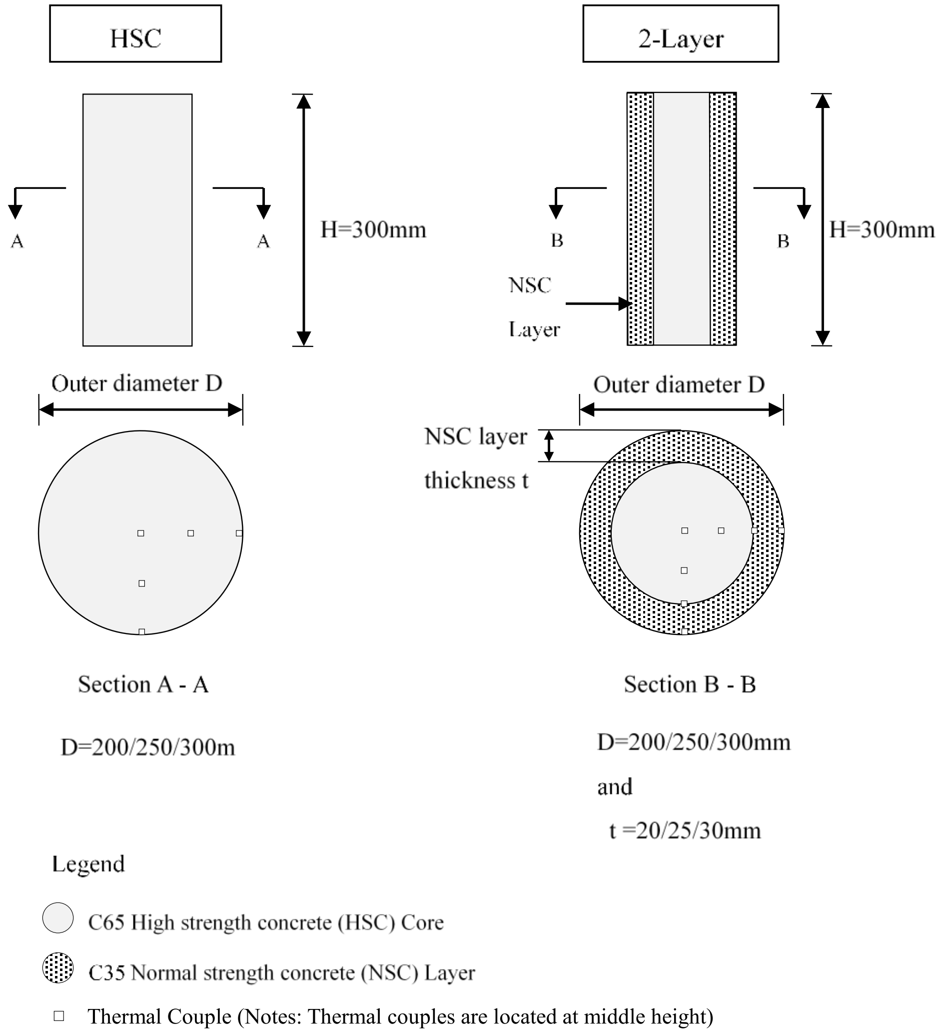


Experimental Studies

Test Specimens

Two identical groups, one for compression tests and the other for fire tests, of totally 12 cylindrical specimens are designed, within each group, three HSC and three 2L specimens are prepared. No thermal couples are needed for the compression tests; therefore, thermal couples are only added in the group for fire tests, locating at middle height of all specimens. Thermal couples are placed in a perpendicular way as shown in Figure 4. The detailed dimensions of specimens can be found in Table 1. The ratio between outer layer thickness and the outer diameter is 0.1.

Figure 4. *Cylindrical Specimens for Experimental Tests*



The casting of 2L specimens have to be done twice: first the HSC core is cast, after one day, demold the HSC core and put it in a larger mold to cast the outer layer, as shown in Figure 5.

Mix Proportions

The mix proportions and compressive strength of C65 and C35 concrete could be referred to in Table 1. As shown in the table, the compressive strength of C65 concrete is only 50.7 MPa, which is much lower than the design strength. Since the concrete used in this test was mixed and cast manually, the low compressive strength is probably due to the poor workmanship such as insufficient mixing and inaccurate material weighing. Loading rate of 265 kN/min is adopted as recommended in British Standard.

Figure 5. *Casting of 2-Layer Specimens*

Table 1. *Mix Proportions for C65 and C35 Concrete*

	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Stone (kg/m^3)	SP (kg/m^3)	Compressive Strength (MPa)
C65	535	162	676	930	0.47	50.7
C35	350	168	720	1070	/	32.9

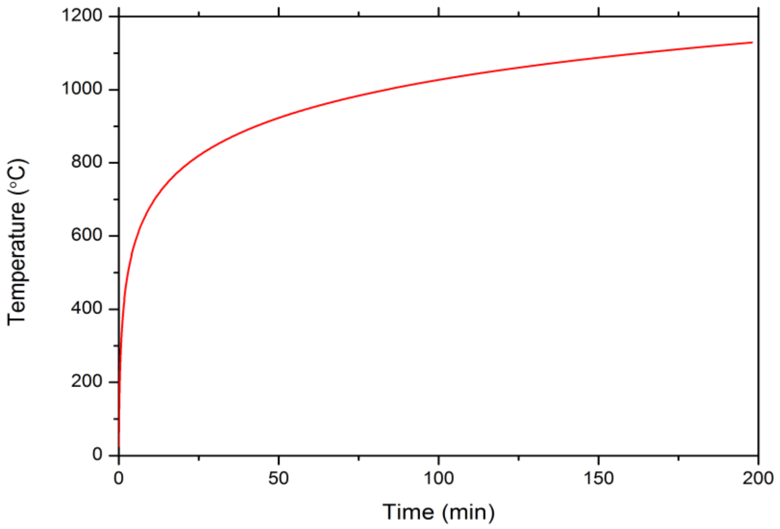
Heating Regime

The electrical furnace could be programmed to follow the ISO 834 standard temperature-time curve (Figure 6), which is represented by the equation:

$$T = 345\log10\ (8t+1) + T_0$$

where T = furnace temperature (℃); t = time in minutes; and T_0 = environmental temperature (taken as 20℃). The highest temperature that can be achieved after the 4-hours' firing is 1150℃ approximately.

Figure 6. *ISO 834 Standard Temperature-Time Curve*

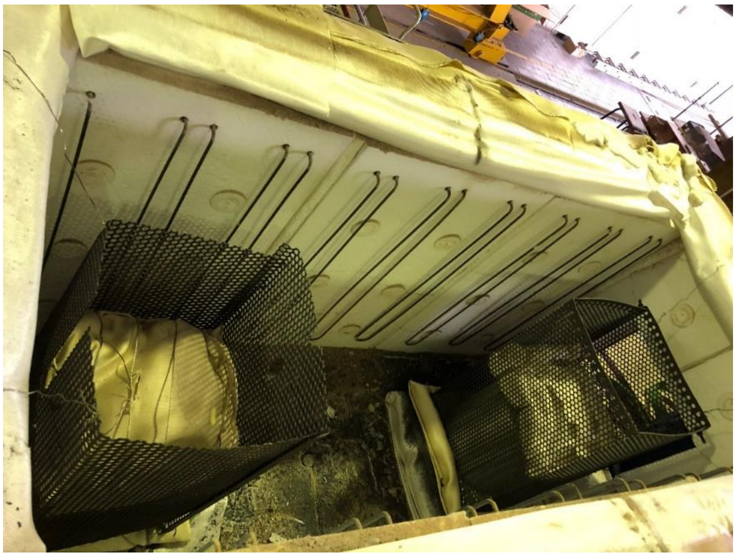


Instrumentation and Test Set-up

Type K Mineral Insulated Thermocouple Sensor with probe length and diameter of 2500mm and 1.6mm respectively, is adopted in this study. The cable length is 5000mm and the maximum temperature that could be detected is 1300℃. The outside and inside views of the electrical furnace for the fire test are shown in Figure 7 and 8. As shown in Figure 8, a steel cage is placed around each specimen to protect the furnace in case of vigorous spalling happens. Specimens are located at the two ends of the furnace. Thermal couples will be connected to the data logger through the openings on two sides of the furnace.

Figure 7. *Outside View of Electrical Furnace*

Figure 8. *Inside View of Electrical Furnace*

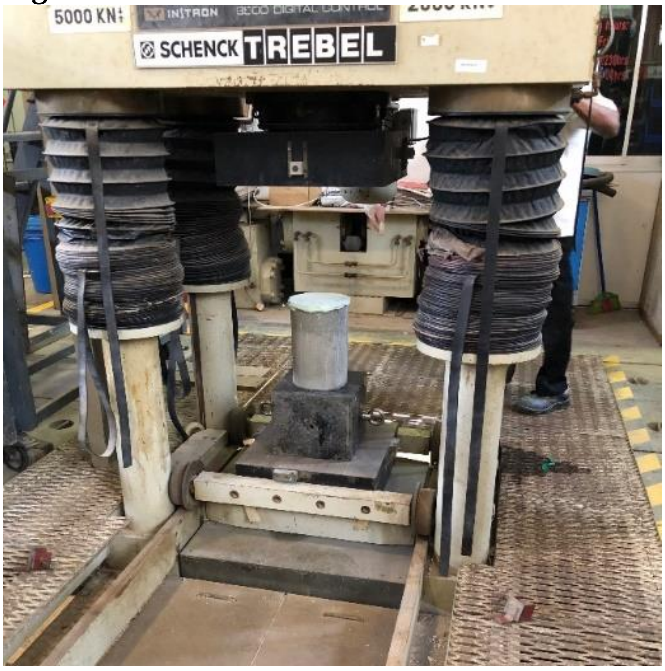


Compression Strength Test Procedures

To obtain the compressive strength of all specimens at ambient temperature and investigate the performance of the bond between HSC core and NSC outer layer of the 2L specimen, compression strength tests were conducted. Dental stone was first applied to smooth the top surface of specimens, as shown in Figure 9. Since the specimens were only 300mm high, a 300mm long steel cube had to be placed on the compression machine to raise the specimens (Figure 10). Compressive loading was then applied to the specimen until failure.

Figure 9. *Specimens Covered with Dental Stone*

Figure 10. *Steel Cube Base*



Fire Test Procedures

Specimen Preparation before Heating

First the top surface of each specimen was insulated with insulating pad made of asbestos wrapped in insulating cloth. Then the specimen was hung into the furnace using crane and placed on another insulating pad to make sure the bottom surface was also insulated. A steel cage was then added and fixed outside the specimen to protect the furnace from damage caused by the spalled concrete. The next step was to cover the top and two sides of furnace and connect thermal couples to the data logger.

Determination of Heating Time

The heating time was mainly determined by the core temperature of the specimen represented by the temperature recorded from the thermal couple located at the center. The heating criterion was that, when the core temperature reached a certain value, the furnace would be shut down immediately. Since most of the explosive spalling occurs in the temperature range of 200℃ to 400℃ (Kanéma et al. 2011, Fu et al. 2005, Fu and Li 2011, Cheng et al. 2004, Kanema et al. 2011), 400℃ was chosen as the threshold value to guarantee the whole specimen would be out of the suspected range of spalling, because the peripheral temperature must be higher than 400℃ when the core temperature reaches 400℃. Supposing that spalling does not occur by this time, we can properly assume that spalling would not occur even if the heating is continued. However, when conducting the fire test of the second pair of specimens, namely the 300mm specimens, we found that 400℃ as the threshold value was unrealistic because it required considerable time and effort to raise the core temperature to 400℃. However, considering that spalling only occurs somewhat 50mm from the surface of the specimen at most, it is unnecessary to heat the whole specimen over 400℃. The threshold value for the core temperature of 250mm and 300mm specimens were therefore changed to 300℃. By this time, the temperature of the outermost 50mm layer would already be far higher than 400℃. In this way, only parts that were most likely to be subjected to spalling were heated till beyond the suspected temperature.

During Heating

The specimens cannot be seen through the furnace, so the sounds throughout the heating process are recorded to indicate whether spalling has already happened.

After Heating

In consideration of safety and protection of the furnace, the furnace was not opened until the gas temperature was lower than 400℃ and based on practical experience, specimens cannot be taken out until they cooled down to lower than 100℃.

Results and Discussion

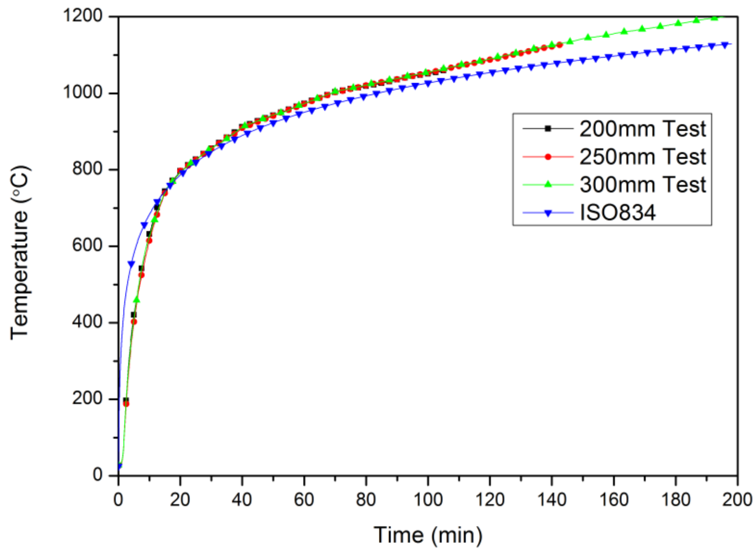
General

The ambient compression strength test results of both specimens are presented in Table 2. Nomenclature is given by "specimen type + specimen outer diameter". For instance, 2L200 stands for the 2-layered specimen with outer diameter of 200mm. The column named "Calculated" is the theoretical values of failure load calculated from the strengths of HSC and NSC. The "Test" column represents the real failure loads recorded from the ambient compression tests. The final column is the ratio between the test and calculated values. By comparing the T/C ratios of 2L and HSC specimens, it is found that the 2L specimens generally have a lower ratio than HSC, which may indicate a strength reduction for 2L specimens due to the interface between HSC core and NSC outer layer. The value of T/C ratio should normally fall in the range of 0.7~1, however, the value of 2L250 specimen is larger than 1, which is assumed to be caused by the different strength and quality of different batches of concrete mix. Another thing to note is that no NSC outer layer fell off throughout the loading process, so it is reasonable to assume that the bond between HSC core and NSC outer layer is strong enough to withstand the loading and avoid the separation of two layers. Specimens were too brittle to perform residual strength test after several hours' heating. The gas temperatures inside the furnace of all three sets of fire tests are compared with the ISO834 standard curve (Figure 9). Results show that the real temperature agrees well with the target temperature for all fire tests.

Table 2. *Ambient Strength Test Results*

Specimen	Total D (mm)	NSC layer t (mm)	Core d (mm)	Calculated (kN)	Test (kN)	T/C Ratio
HSC200	200	0	200	1592.30	1554	0.98
2L200	200	20	160	1390.91	1051	0.76
HSC250	250	0	250	2487.96	1934	0.78
2L250	250	25	200	2173.30	2233	1.03
HSC300	300	0	300	3582.67	3009	0.84
2L300	300	30	240	3129.55	2304	0.74

Figure 11. *ISO834 Curve VS Real Gas Temperatures*



Fire Test Results Analysis

Figure 10 to 15 illustrate the comparison between real temperatures recorded from thermal couples embedded in the specimens and simulation results by ABAQUS. Real test curve is named by "Specimen type + outer diameter + thermal couple position (distance to the center of specimen)". Except from the center, every other position should originally have two thermal couples embedded, however, due to manufacture or heating reasons, some of the thermal couples were broken and therefore data is missing for some of the positions. The simulation curves are named by "thermal couple position + sim". For both HSC and 2L specimens, a plateau is observed generally at the temperature between 100°C and 150°C, and the nearer to the center, the longer the plateau continues. This phenomenon is very likely to be caused by the evaporation and diffusion of free water in the concrete pores (Phan 2008, Lie and Celikkol 1991). When the temperature reaches around 105°C, free water starts to evaporate and migrate towards the center of the specimen due to the pore pressure gradient. The transfer of heat in the concrete is retarded, as a result of energy being absorbed in the process of evaporation and migration, leading to a decrease in the rate of temperature rise or a nearly constant temperature period in the early stage of fire tests. The plateau ends when the concrete temperature rises to about 150°C, by which time most of the water vapor would have escaped through the concrete surface and stop migrating. Regarding the HSC and 2L specimens with the same outer diameter, it is found that the temperatures at corresponding positions have similar values and trends, which may indicate the interface between the HSC core and NSC outer layer does not have a significant effect on the heat transfer in concrete. The NSC outer layer takes effect in preventing the heat from attacking the HSC core, which improves the performance of HSC under fire to some extent.

Figure 12. *Comparison of HSC200 Specimen*

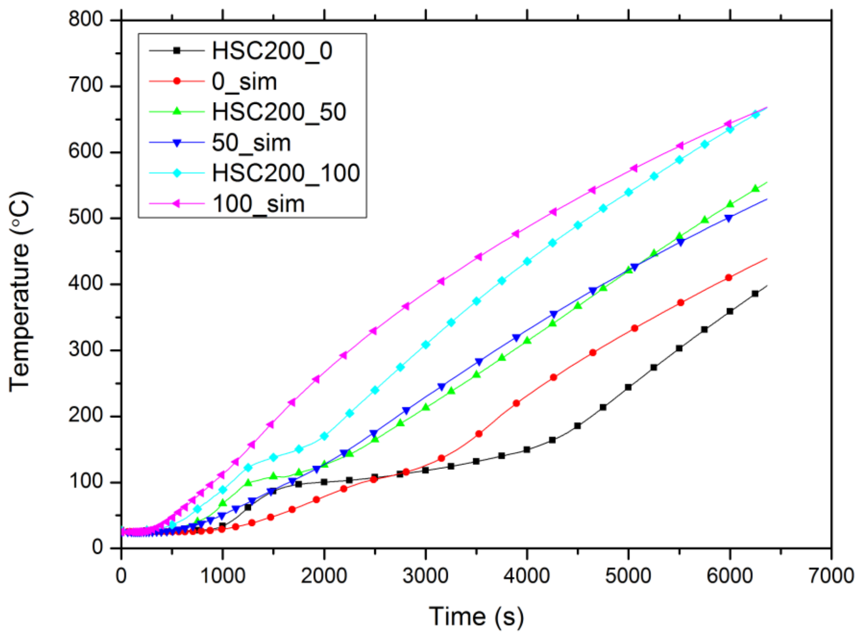


Figure 13. *Comparison of 2L200 Specimen*

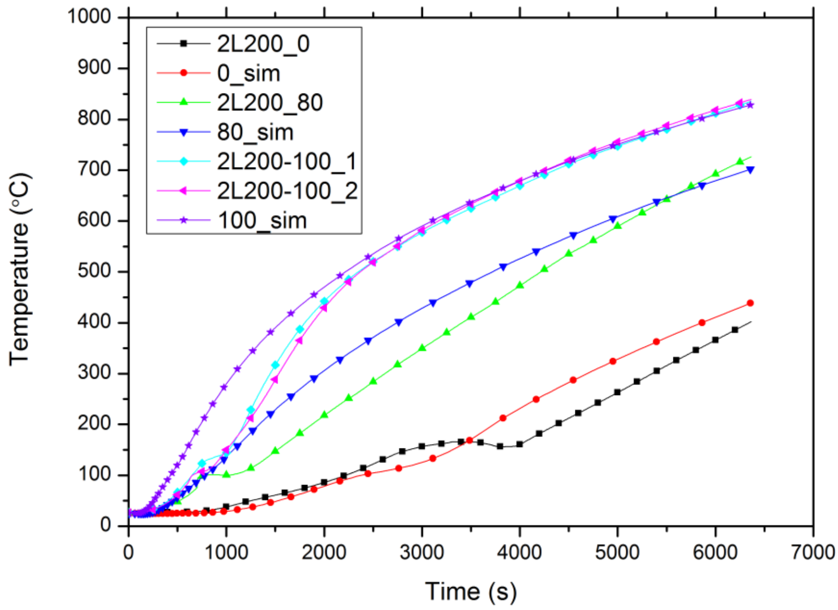


Figure 14. *Comparison of HSC250 Specimen*

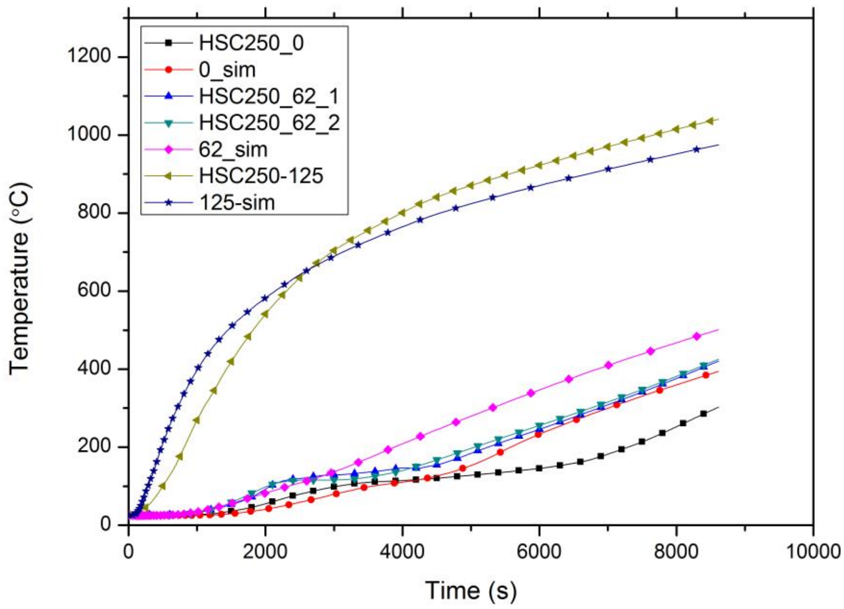


Figure 15. *Comparison of 2L250 Specimen*

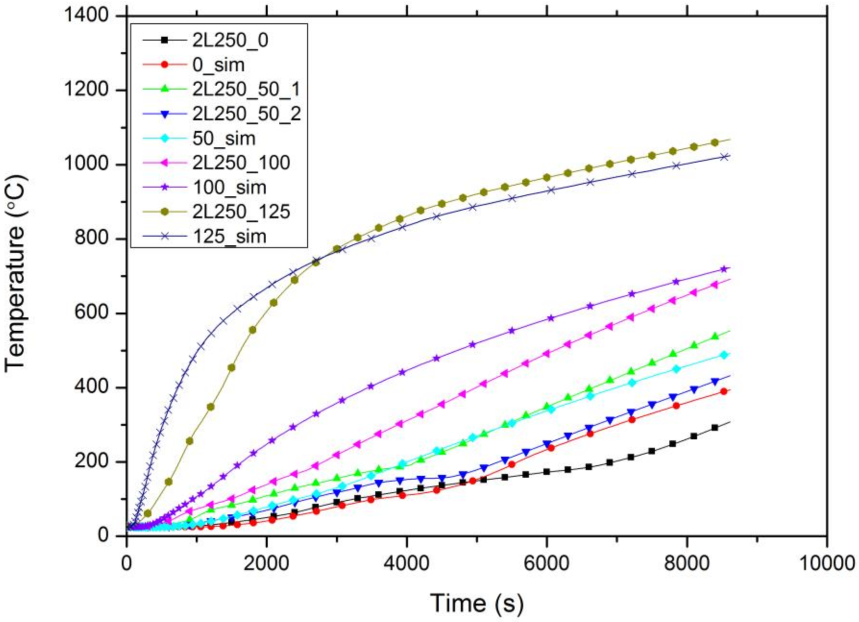


Figure 16. *Comparison of HSC300 Specimen*

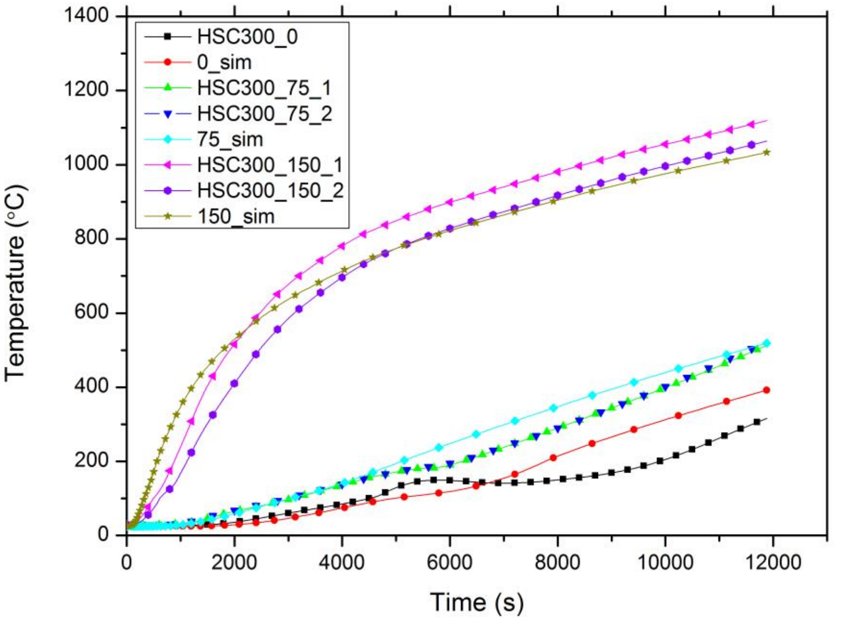
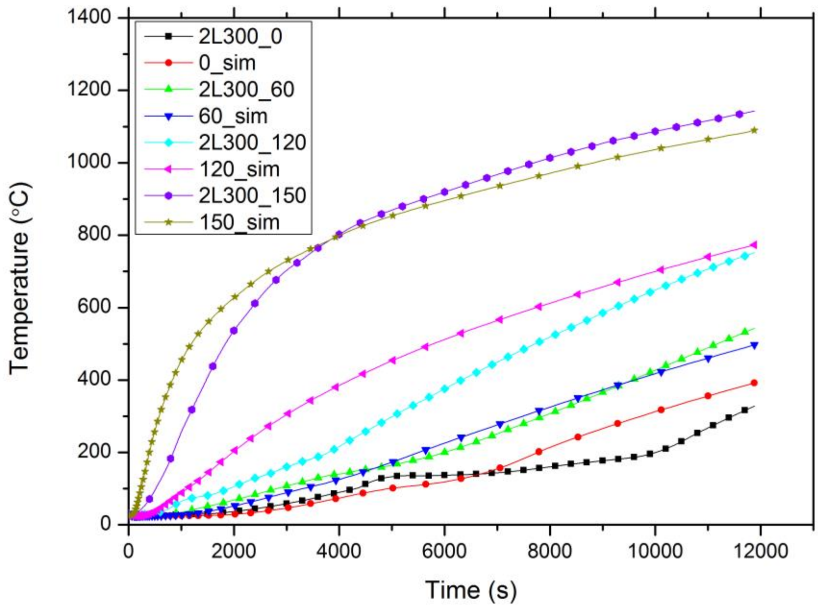


Figure 17. *Comparison of 2L300 Specimen*



Spalling Observation

No explosive spalling was observed for all HSC and 2L specimens. The poor workmanship for casting concrete leading to the low strength and high permeability of HSC could be the main reason which prevents the happening of explosive spalling in HSC specimens. Water vapor inside the concrete was released through the pores under high temperature, pore pressure was not able to build up to exceed the tensile strength of concrete. As a result, explosive spalling was avoided for specimens. However, sounds of cracks and pops were continuously heard during the heating of HSC specimens, which may suggest the occurrence of minor spalling in the HSC specimens. NSC outer layer of 2L specimens remained intact after heating, except that the outer layer of 200mm specimen fell off when hanging out from furnace. The NSC layer of the 200mm 2L specimen is only 20mm thick, which caused certain difficulties to the casting and manual vibration of the outer layer. Consequently, the bond between HSC and NSC is relatively weak and it is further weakened under elevated temperatures. It is deduced that the minimum thickness of NSC outer layer should be no less than 20mm, reasoning that once the thickness is less than 20mm it would be difficult to cast and vibrate the outer layer and the bond between the two layers would become too weak. Visible cracks developed on the surface of all specimens.

Post Cooling Behavior

Post cooling spalling occurred when the 300mm HSC specimen was taken out from furnace and cooled down in the ambient temperature. As mentioned above, thermal chemical spalling consists of sloughing-off spalling at extremely high temperature and post cooling spalling after exposing to elevated temperature (Xing et al. 2011, Annerel and Taerwe 2009). The main cause of thermal-chemical spalling is the break-down of aggregate cement bond, such as calcium silicate hydroxide and calcium hydroxide (Schneider 1988). The threshold temperature of thermal-chemical spalling is relatively high at around 750℃. The 300mm specimens were heated for the longest time at around 3.5 hours, and the core temperature would continue to rise for a period of time even the furnace is shut down. Therefore, the highest core temperature and gas temperature recorded was 713℃and 1213℃ respectively, which means most part of the specimen has been heated up to over 700℃. Thus, the occurrence of post cooling spalling can be considered reasonable.

Conclusions

The bond between the HSC core and NSC outer layer is assumed to be strong enough to withstand the loading and avoid separation of the two layers based on the ambient compression test results. However, a strength reduction may exist for the 2L specimens due to the interface between the HSC core and NSC outer layer. A plateau is observed at around 100℃ to 150℃, which is caused by the free water evaporation and diffusion inside the concrete pores. The effect of the interface between HSC and NSC on heat transfer in concrete is not significant. And the NSC outer layer is proved to be effective in preventing the heat from attacking the HSC core. No explosive spalling was observed for all specimens. Yet sounds of cracks and pops were heard during the heating process of HSC specimens, which may indicate the occurrence of minor spalling. Post cooling spalling, whose threshold temperature is at around 750℃, occurred when the 300mm HSC specimen was taken out from furnace and cooled down in the ambient temperature. The highest core temperature and gas temperature of the 300mm HSC specimen recorded was 713℃and 1213℃respectively. In practical construction projects, the thickness of NSC outer layer is recommended to be no less than 20mm, owing to the fact that it would be difficult to cast and vibrate the outer layer concrete and the bond between the two layers would become too weak.

Acknowledgments

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The New Australian Concrete Structures Standard AS 3600:2018 – Aspects of its Complexity and Effectiveness

By Sanaul Chowdhury[*] & Yew-Chaye Loo[†]

Providing design guides, the first of the AS 3600 standard series, Australian Standard for Concrete Structures AS 3600-1988 was published in March 1988. Since then, AS 3600 has been revised four times and published consecutively at between six to nine-year intervals as AS 3600-1994, AS 3600-2001, AS 3600-2009 and the latest, AS 3600-2018. The changes and/or updates made in AS 3600-2018 are mainly in the following requirements:

- *Stress-block configuration for bending analysis and design of reinforced and prestressed members*
- *Shear and torsional strengths of members*
- *Values of capacity reduction factor, ϕ, for different member strengths*
- *Effective moment of inertia for deflection calculations*

Most of the abovementioned modifications have resulted in more complicated procedures and additional computational efforts. Academically, such added complexity might be considered as a disciplinary upgrade. On the other hand, the practitioners deserve to be advised of the effectiveness, or worthiness, of such an advance. In each of the concerned topics, analysis and design calculations have been carried out using the updated specifications given in AS 3600-2018, as well as those available in the superseded AS 3600-2009. Based on the numerical data and design outcomes, observations are made in this paper regarding the complexity and effectiveness of this the latest version of Australia's premier concrete structures code.

Keywords: *AS 3600-2018, Australian Standards, Complexities, Concrete Structures, Design Effectiveness.*

Introduction

The ultimate strength theory underpins the analysis and design of reinforced and prestressed concrete structures and has been since the promulgation of Australia's Concrete Structures Standard, Australian Standard (AS) 3600-1988 *Concrete Structures*. The first of this AS 3600 series, was published in March 1988. In line with European practices, it was a unified code covering reinforced and prestressed concrete structures. In effect, AS 3600-1988 *Concrete Structures* was the revised and amalgamated version of AS 1480-1982 *SAA Concrete Structures Code* and AS 1481-1978 *SAA Prestressed Concrete Code*, which it then superseded. Limit state design philosophy was adopted in AS 3600-1988. In practice, especially in strength design, engineers familiar with AS 1480-1982 could make the changeover without too much difficulty. Many

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of the design equations for shear, torsion, slabs and columns were changed, but the strength design procedure was basically the same, that is, to ensure

$$\phi R_u \geq S^* \quad (1)$$

where for a given section of any structural member to be designed, S^* was the 'action effect' or axial force, moment, shear or torsion due to the most critical combination of the external service loads, each multiplied by a corresponding load factor; R_u was the computed ultimate resistance (or strength) of the member at that section against the said type of action effect; and ϕ was the capacity reduction factor specified for the type of ultimate strength in question.

Since 1988, AS 3600 has been revised and updated four times and published consecutively at approximately six to nine-year intervals as AS 3600-1994, AS 3600-2001, AS 3600-2009, and the latest AS 3600-2018. However, the limit state design philosophy remains unchanged in the latest version of the Standard in which Clause 2.2.2 states that

$$R_d \geq E_d \quad (2)$$

where $R_d = \phi R_u$ is the 'design capacity', and $E_d = S^*$, the design action effect.

In AS 3600-2001, which appeared in 2002, N-grade or 500 MPa steel was specified, leading to modifications in serviceability specifications and other consequential changes. In AS 3600-2001, an additional strength grade for concrete was introduced with the characteristic compressive strength $f'_c = 65$ MPa. Two more grades were provided in AS 3600-2009, i.e. $f'_c = 80$ MPa and 100 MPa. This has resulted in modification to many of the design equations. However, these design equations are further modified and/or made more complex in some cases in AS 3600-2018.

The changes and/or updates made in AS 3600-2018 are mainly in the following requirements:

- Stress-block configuration for the analysis and design of reinforced and prestressed members in bending.
- Values of capacity reduction factor, ϕ, for different member strengths.
- Shear and torsional strengths of members.
- Effective moment of inertia for deflection calculations.

Being a rather mature discipline, research worldwide on the mechanics and strength of concrete structures is sustaining a state of diminishing return. Australia is no exception. The abovementioned modifications have resulted in more complicated procedures and added computational efforts. Academically, such increased complexity might be considered as a disciplinary upgrade. On the other hand, the practitioners deserve to be advised of the effectiveness, or worthiness, of such an advance.

In view of the above, for each of the concerned topics, analysis and design calculations have been carried out using the updated specifications given in AS 3600-2018, as well as those available in the superseded AS 3600-2009. Based on the numerical data and design outcomes, observations are made in this paper regarding the complexity and effectiveness of this the latest version of Australia's premier concrete structures code.

Concrete Stress Block and Capacity Reduction Factor – A Review

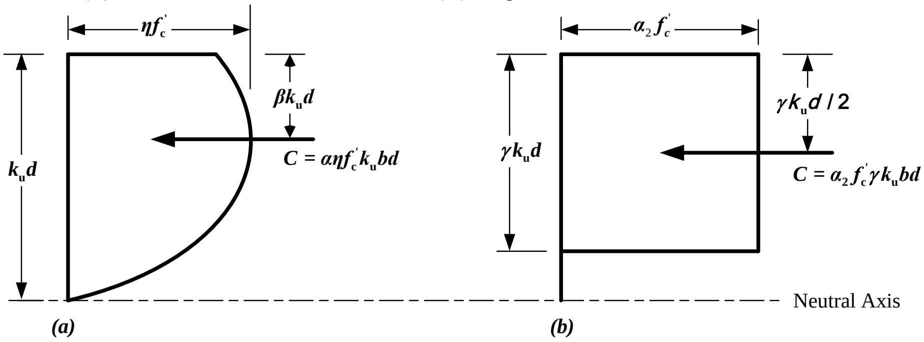
Design of reinforced concrete for flexure is traditionally performed using a rectangular stress block that simulates compressive stresses in concrete. Because of its simplicity and relative accuracy, the use of the rectangular stress block is recommended in many major national concrete structures codes, including AS 3600 series. It is well established that the stress-strain characteristics of concrete change with strength (Ibrahim and MacGregor 1997, Kaar et al. 1978, Nedderman 1973, Ozbakkaloglu and Saatcioglu 2004, Tan and Nguyen 2004, 2005, Barchi et al. 2010, Yan and Au 2010, Zhu and Su 2010, Ho 2011). Therefore, the rectangular stress block adopted for normal-strength concretes in earlier versions of AS 3600 may not be applicable to high strength concrete. Thus, in AS 3600-2009, with the introduction of higher strength grades of concrete, a new rectangular stress block was incorporated. The stress block parameters have been further modified in AS 3600-2018.

Although the strength design procedure was unchanged from AS 1480-1982 and AS 1481-1978, the recommended load factors were generally lower in AS 3600 series than previously specified. However, accompanying these lower load factors were the corresponding reduced values of ϕ. A probabilistic-based analytical model was adopted to re-evaluate the reliability of the then new design procedure. Unfortunately, actual failure statistics were inadequate for the probabilistic analysis to produce a new and more reliable procedure (in terms of load factors and ϕ). Instead, the new procedure was calibrated simply using designs based on the old AS 1480-1982 code. In simplistic terms, the codes prior to AS 3600 series and after applied in parallel should lead to the same design. However, the values of ϕ have been increased in AS 3600-2018 to address this issue.

Complexities

The widely accepted 'actual' stress block is as shown in Figure 1(a). The factor $\eta < 1$ accounts for the difference between the crushing strength of concrete cylinders and the concrete in the beam; α and *ß*, each being a function of f_c', define the geometry of the stress block. Empirical but complicated formulas have been given for η, α and *ß.* Although the concept of the curved stress block was acknowledged as an advance, it was tedious to apply. The equivalent (rectangular) stress block, as shown in Figure 1(b), was so defined that its use would give the same M_u as that computed using the 'actual' stress block.

Figure 1. (a) *Actual Stress Block* and (b) *Equivalent Stress Block*



In AS 3600-2009, α_2 and γ for all section types were given as:

$$\alpha_2 = 1.0 - 0.003 f'_c \quad \text{but} \quad 0.67 \le \alpha_2 \le 0.85 \qquad (3)$$

$$\gamma = 1.05 - 0.007 f'_c \quad \text{but} \quad 0.67 \le \gamma \le 0.85 \qquad (4)$$

In AS 3600-2018, these are changed to:

$$\alpha_2 = 0.85 - 0.0015 f' \quad \text{but} \quad \alpha_2 \ge 0.67 \qquad (5)$$

For circular sections, α_2 is to be reduced by 5% and for any section for which width reduces from the neutral axis towards the compression face, α_2 is to be reduced by 10%.

On the other hand, for all section types,

$$\gamma = 0.97 - 0.0025 f'_c \quad \text{but} \quad \gamma \ge 0.67 \qquad (6)$$

In AS 3600-2009, the capacity reduction factor ϕ was given as

$$\phi = 1.19 - 13 k_{uo} / 12 \qquad (7)a$$

but for beams with Class N reinforcement only

$$0.6 \le \phi \le 0.8 \qquad (7)b$$

and for beams with Class L reinforcement

$$0.6 \le \phi \le 0.64 \qquad (7)c$$

In Equation (7)a, $k_{uo} = \frac{k_u d}{d_o}$ in which d_o is the distance between the extreme compression fibre and the centroid of the outermost layer of the tension bars.

In AS 3600-2018, ϕ values are changed to:

$$\phi = 1.24 - 13k_{uo} / 12 \quad (8)a$$

but for beams with Class N reinforcement only

$$0.65 \le \phi \le 0.85 \quad (8)b$$

and for beams with Class L reinforcement

$$\phi = 0.65 \quad (8)c$$

Effectiveness

Analysis and design calculations have been carried out using the updated specifications given in AS 3600-2018 and those available in the superseded AS 3600-2009 for several problems. These helps investigate the effectiveness of introducing the complexities as described above in determining α_2, γ and ϕ. The results are presented in detail elsewhere (Loo and Chowdhury 2018).

As a demonstration, for a singly reinforced rectangular section with b = 250 mm, d = 500 mm, f_c' = 50 MPa, and Class N reinforcement only (f_{sy} = 500 MPa), the reliable moment capacities for the following reinforcement cases were calculated using provisions of both AS 3600-2009 and AS 3600-2018:

(a) A_{st} = 1500 mm^2
(b) A_{st} = 9000 mm^2
(c) a 'balanced' design
(d) with the maximum allowable reinforcement ratio (p_{all})
(e) A_{st} = 4500 mm^2.

The results are tabulated in Table 1 for comparison. As can be seen from Table 1, the ultimate moment capacities for different reinforcement cases differ very little while reliable moment capacities varying to slightly larger extents mainly because of increase in ϕ values in AS 3600-2018. Similar minor variations in moment capacities were observed for all other problems even for non-standard and circular sections (Loo and Chowdhury 2018).

As for design examples, these changes made no difference at all in reinforcement requirements and sectional dimensions (Loo and Chowdhury 2018) for any of the worked problems which include all section types (rectangular and flanged) and reinforcement details (singly- and doubly-reinforced).

Table 1. *Comparison between AS 3600-2009 and AS 3600-2018 for the Analysis Problem*

Reinforcement Case (A_{st} values)	As per AS 3600-2009			As per AS 3600-2018		
	M_u (kNm)	ϕ	ϕM_u (kNm)	M_u (kNm)	ϕ	ϕM_u (kNm)
(a) A_{st} = 1500 mm^2	348.5	0.8	278.8	346.0	0.85	294.1
(b) A_{st} = 9000 mm^2	964.2	0.6	578.5	978.5	0.65	636.0
(c) balanced $p_t = p_B$	819.5	0.6	491.7	858.7	0.65	558.2
(d) maximum $p_t = p_{all}$	639.6	0.757	484.2	680.4	0.807	549.1
(e) A_{st} = 4500 mm^2	840.7	0.6	504.4	860.4	0.65	559.3

Design for Shear and Torsion

Shear behaviour of reinforced concrete beams is very complicated due to many parameters such as concrete compressive strength, stirrup ratio, shear span-to-depth ratio, longitudinal reinforcement ratio, and so on (Lee et al. 2010, Labib et al. 2013, Mofidi and Chaallal 2014, Chiu et al. 2016, El-Sayed and Shuraim 2016, Zhang et al. 2017, Jude et al. 2018). It is, therefore, hard to evaluate shear strength of reinforced concrete beams. Even shear design provisions around the world are much different through each other, even from theoretical perspective, especially for reinforced concrete beams with stirrups (Eurocode 2 2004, ACI 318 2014, CSA A23.3 2014, AS 3600 2018). Similar is the case for torsion design.

Complexities and computational efforts introduced in AS 3600-2018 are most severe for design of reinforced and prestressed concrete for shear and torsion. Apart from the required increase in capacity reduction factor (ϕ) for shear and torsion consideration from 0.7 to 0.75, some substantial changes have been introduced. These, together with their effectiveness, are discussed in the following sections.

Complexities

The nominal maximum shear force that can be carried by a beam is limited by the crushing strength of the web, $V_{u.max}$, was given in AS 3600-2009 as

$$V_{u.max} = 0.2 f'_c b_w d_o \tag{9}$$

where b_w is the width of the web of the beam.

On the other hand, $V_{u.max}$ is to be calculated in a much more complicated manner in AS 3600-2018, as

$$V_{u.max} = 0.55\left[f'_c b_w d_v \left(\frac{\cot \theta_v}{1+\cot^2 \theta_v} \right)\right] \tag{10}$$

where effective shear depth, d_v, shall be taken as the greater of 0.72D or 0.9d and the angle of inclination of the compression strut (θ_v) shall be calculated as

$$\theta_v = (29 + 7000\varepsilon_x) \tag{11}$$

in which, the longitudinal strain in concrete for shear, ε_x, at the mid-depth of the section is calculated as

$$\varepsilon_x = \frac{|M^*/d_v| + |V^*| + 0.5N^*}{2E_s A_{st}} \leq 3.0 \times 10^{-3} \tag{12}$$

M^* and V^* are absolute values and $M^* \geq V^* d_v$ and N^* is the axial force acting on the section and is taken as positive for tension and negative for compression.

Alternatively, θ_v may be taken as 36º for $N^* = 0$, $f_{sy} \leq 500$ MPa, $f'_c \leq 65$ MPa and maximum aggregate size not less than 10 mm.

Concrete contribution to shear strength, V_{uc}, is given by the following in AS 3600-2009:

$$V_{uc} = \beta_1 \beta_2 \beta_3 b_w d_o f_{cv} \sqrt[3]{\frac{A_{st}}{b_w d_o}} \tag{13}$$

where β_1, β_2 and β_3 can be computed using simple formulas and/or taken as equal to 1, and $f_{cv} = \sqrt[3]{f'_c}$.

In AS 3600-2018, the determination of V_{uc}, requires much more computational efforts in a rather complex way. Or, V_{uc}, is given as

$$V_{uc} = k_v b_w d_v \sqrt{f'_c} \tag{14}$$

where $\sqrt{f'_c}$ is not to exceed 8.0 MPa, the strut angle θ_v is calculated using Equations (11) and (12) as above and k_v is determined as elaborated below.

(a) For $A_{sv} < A_{sv.min}$:

$$k_v = \left[\frac{0.4}{1 + 1500\varepsilon_x}\right]\left[\frac{1300}{1000 + k_{dg} d_v}\right] \tag{15}$$

where

(i) $f'_c \leq 65$ MPa and not light-weight concrete

$$k_{dg} = \left[\frac{32}{(16+a)}\right] \geq 0.8 \tag{16}$$

a is the maximum nominal aggregate size and for a not less than 16 mm, k_{dg} may be taken as 1.0.

(ii) f'_c > 65 MPa or light-weight concrete

$$k_{dg} = 2.0 \tag{17}$$

(b) For $A_{sv} > A_{sv.min}$:

$$k_v = \left[\frac{0.4}{1+1500\varepsilon_x}\right] \tag{18}$$

Alternatively, for $N^* = 0$, $f_{sy} \leq 500$ MPa, $f'_c \leq 65$ MPa and maximum aggregate size not less than 10 mm, k_v may be determined as follows.

(a) For $A_{sv} < A_{sv.min}$:

$$k_v = \left[\frac{200}{1000+1.3d_v}\right] \leq 0.10 \tag{19}$$

(b) For $A_{sv} > A_{sv.min}$:

$$k_v = 0.15 \tag{20}$$

Finally, transverse shear reinforcement is to be provided in all regions where $V^* > \phi V_{uc}$ or in which the overall depth of the member $D \geq 750$ mm.

For torsional design, even though the basic principles were still the same, the computations and formulas used are made a lot more complicated – not to mention the extra computational efforts required.

In AS 3600-2009, for combined torsion and shear and for all section types,

$$T^* \leq \phi T_{u,max}\left(1-\frac{V^*}{\phi V_{u,max}}\right) \tag{21}$$

where $V_{u.max}$ is calculated using Equation (9) and the maximum capacity of a beam in torsion, $T_{u.max}$ is given by

$$T_{u,max} = 0.2 f'_c J_t \tag{22}$$

In Equation (22), J_t is the torsional modulus and is given by some simple formulas.

In AS 3600-2018, on the other hand, for combined shear and torsion, the following are to be satisfied.

(a) For box sections:

(i) Where wall thickness $t_w > A_{oh}/u_h$

$$\frac{V^*}{b_w d_v} + \frac{T^* u_h}{1.7 A_{oh}^2} \leq \frac{\phi V_{u.max}}{b_w d_v} \tag{23}$$

(ii) Where wall thickness $t_w \leq A_{oh}/u_h$

$$\frac{V^*}{b_w d_v} + \frac{T^*}{1.7 t_w A_{oh}} \leq \frac{\phi V_{.u.max}}{b_w d_v} \tag{24}$$

(b) For other sections:

$$\sqrt{\left[\frac{V^*}{b_w d_v}\right]^2 + \left[\frac{T^* u_h}{1.7 A_{oh}^2}\right]^2} \leq \frac{\phi V_{u.max}}{b_w d_v} \tag{25}$$

where

A_{oh} = areas enclosed by centre-line of exterior closed transverse torsion reinforcement, including area of holes (if any)

u_h = perimeter of the centre-line of the closed transverse torsion reinforcement

$V_{u.max}$ is calculated using Equation (10) but for the determination of θ_v, the longitudinal strain in the concrete at the mid-depth of the section, ε_x , subjected to shear and torsion is determined as

$$\varepsilon_x = \frac{\left|\frac{M^*}{d_v}\right| + \sqrt{\left|V^*\right|^2 + \left[\frac{0.9 T^* u_h}{2 A_o}\right]^2} + 0.5 N^*}{2 E_s A_{st}} \leq 3.0 \times 10^{-3} \tag{26}$$

In Equation (26), A_o = area enclosed by shear flow path, including any area of holes therein and N^* is taken as positive for tension and negative for compression. Also, M^* and V^* are absolute values and

$$M^* \geq d_v \sqrt{\left|V^*\right|^2 + \left[\frac{0.9 T^* u_h}{2 A_o}\right]^2} \tag{27}$$

Also, for consideration of torsional effects, the plain-concrete beam strength in pure torsion, T_{uc}, was given in AS 3600-2009 as

$$T_{uc} = J_t \left(0.3\sqrt{f'_c}\right) \tag{28}$$

But in AS 3600-2018, this was replaced by torsional cracking moment, T_{cr}, and was given by a more complicated formula as

$$T_{cr} = \left(0.33\sqrt{f'_c}\right)\frac{A_{cp}^2}{u_c} \tag{29}$$

where

A_{cp} = total area enclosed by the outside perimeter of the concrete cross-section
u_c = the length of the outside perimeter of the concrete cross-section.

Finally, for the transverse reinforcement (ties) to be fully effective, longitudinal bars are needed. Thus, longitudinal torsional steel in addition to the main reinforcement for bending must be provided in the bending tensile and compressive zones. Formulas for calculating the additional longitudinal reinforcement requirements for torsion, in both the tensile and compressive zones, are also made much more complicated in AS 3600-2018. For brevity, these new changes are not reproduced herein. Interested readers may refer to the Standard itself (AS 3600-2018) for details.

Effectiveness

Calculations for design of reinforced concrete for shear and torsion have been carried out using the updated specifications given in AS 3600-2018, as well as those available in the superseded AS 3600-2009 for several practical problems. These are presented in detail elsewhere (Loo and Chowdhury 2018).

A summary of some of the worked problems for shear design using AS 3600-2009 and AS 3600-2018 is presented in Table 2 for comparison.

Table 2. *Comparison between AS 3600-2009 and AS 3600-2018 for Shear Design Problems*

Problem No.	Design V^* (kN)	As per AS 3600-2009			As per AS 3600-2018		
		$V_{u.max}$ (kN)	V_{uc} (kN)	Final Design	$V_{u.max}$ (kN)	V_{uc} (kN)	Final Design
1	137.73	380.0	141.6	R10@ 225 mm	802.7	48.6	R10@ 125 mm
2	248.76	430.0	108.2	R10@ 75 mm	506.1	58.05	R10@ 75 mm
3	537.73	987.0	218.2	N16@ 285 mm	1112.2	127.6	N16@ 245 mm
4	334.61	1658.9	260.3	N12@ 300 mm	1876.5	190.4	N12@ 300 mm
5	583.14	1570.6	89.5	N10@ 85 mm	1742.8	229.4	N10@ 145 mm
6	478.36	1316.3	210.1	N10@ 155 mm	1474.5	154.5	N10@ 125 mm
7	130.47	486.4	139.8	R10@ 225 mm	542.3	55.0	R10@ 145 mm
8	876.60	2165.8	394.7	N12@ 165 mm	2375.4	241.0	N12@ 130 mm
9	228.69	420.0	98.3	R10@ 85 mm	494.3	56.7	R10@ 90 mm
10	1180.7	2030.4	328.7	N12@ 75 mm	2392.6	101.9	N12@ 45 mm
11	476.0	1776.0	256.5	N12@ 195 mm	1844.3	311.4	N12@ 300 mm
12	325.17	998.4	23.3	N12@ 180 mm	1168.2	132.7	N12@ 245 mm
13	138.31	430.0	108.2	R10@ 250 mm	497.4	69.7	R10@ 190 mm

As obvious in Table 2, the final designs for shear varied rather little for most of the problems. In fact, for the lower range of design shear values, where the maximum spacing for shear reinforcement allowed by the Standard governed, there are no difference in the final design. Cases where the final design varied significantly are beams subjected to large axial forces together with design shear forces. For example, Problems 5, 10, 11, 12 and 13 are subjected to very large inclined forces. Interested readers may find further details elsewhere (Loo and Chowdhury 2018).

Similar observations have also been made for torsion design in that little or no variations can be found in the outcomes.

Deflection

It has been concluded in a comparative study of nine analytical methods that the effective moment of inertia approach is a convenient and accurate one for deflection calculations (Loo and Wong 1984). It is convenient because the standard deflection formulas are readily applicable with modifications only to the bending rigidity term or *EI*.

For a cracked reinforced concrete beam, E is replaced by the modulus of elasticity for concrete, E_c, and for I an effective value I_{ef} can be used where in general,

$$I_{cr} \le I_{ef} \le I_g \tag{30}$$

in which I_g is the gross moment of inertia of the uncracked beam section and I_{cr} is that of a fully cracked beam.

Complexities

The empirical Branson formula for calculating the effective moment of inertia (I_{ef}) has been adopted in the AS 3600-2009 and several other major codes of practice including that of the American Concrete Institute (see Loo and Wong 1984). Taking into consideration the stiffening effects of the concrete in tension between cracks (i.e. tension stiffening), the formula is explicit and all-encompassing. That is

$$I_{ef} = I_{cr} + (I_g - I_{cr})\left(\frac{M_{cr}}{M_s}\right)^3 \le I_{ef.max} \tag{31}$$

where $I_{ef.max} = I_g$ for $p_t \ge 0.005$ and $I_{ef.max} = 0.6 I_g$ for $p_t < 0.005$, which indicates that the Branson formula in its original form underestimates the deflection of very lightly reinforced beams (see Gilbert 2008).

The quantity M_s is the maximum bending moment at the section due to the short-term serviceability load under consideration, and M_{cr} is the cracking moment.

In AS 3600-2018, the formula for calculating I_{ef} is modified as follows with the same limiting values for $I_{ef.max}$ as in Equation (31):

$$I_{\mathrm{ef}} = \frac{I_{\mathrm{cr}}}{1-\left(1-\frac{I_{\mathrm{cr}}}{I_{\mathrm{g}}}\right)\left(\frac{M_{\mathrm{cr}}}{M_{\mathrm{s}}}\right)^2} \leq I_{\mathrm{ef.max}} \quad (32)$$

Effectiveness

To investigate the effectiveness of the changes made to the I_{ef} formula, calculations for several deflection problems have been made using the provisions given in AS 3600-2018, as well as those available in the superseded AS 3600-2009. The outcomes are detailed elsewhere (Loo and Chowdhury 2018).

As a demonstration, the midspan deflection of a simply supported beam is calculated. With L_{ef} = 10 m, b = 350 mm, d = 580 mm, D = 650 mm and p_{t} = 0.01, the beam is under a combined dead load including self-weight (g = 8 kN/m) and live load (q = 8 kN/m). The values for E_{c}, E_{s} and f'_{c} are taken as 26000 MPa, 200000 MPa and 32 MPa, respectively and the beam is assumed to form part of a domestic floor system with the shrinkage effects ignored.

A comparison of results shows that using AS 3600-2009, the value of I_{ef} is 3750 × 10^6 mm^4. This is very close to AS 3600-2018 value of 3717 × 10^6 mm^4. Similarly, the corresponding midspan deflections are 18.2 mm and 18.3 mm.

Likewise, little or no variations in deflection results were observed for all other problems attempted in the said investigation.

Conclusions

Significant changes and/or updates have been made in AS 3600-2018, the latest Australian Standard for Concrete Structures. These are mainly in the requirements for configuring the stress-block, calculating the capacity reduction factor ϕ, evaluating the shear and torsional strengths of concrete members, as well as in estimating the effective moment of inertia I_{ef}.

These modifications have resulted in more complicated procedures requiring added computational efforts. Comparisons of results tend to show that such additional efforts have in most cases produced no significant difference in outcomes from the superseded AS 3600-2009. Where there are differences, the new Standard would lead to less conservative designs.

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Efficient Edge Detection by Adapting Artificial Bee Colony Algorithm

By Ricardo Contreras Arriagada[*], Ricardo Contreras Apablaza[†] & Maria Angélica Pinninghoff[‡]

The problem of edge detection considers two stages: localisation and identification. Localisation is the search of pixels in an image; identification is the process of deciding whether a pixel belongs to an edge. The Canny edge detector technique is effective in identification; the process itself involves the analysis of every pixel that belongs to an image. Similarly, the artificial bee colony (ABC) algorithm performs an efficient localisation of food sources by simulating the foraging behaviour of a honey bee swarm. In this proposal we integrate ABC algorithm and Canny to create ABC-ED, an efficient edge detector algorithm that reduces the quantity of pixels to analyse, in order to detect its edges. We used the BSDS500 dataset for experimentation; our results show it is not necessary to analyse every pixel in the image to detect the same edges compared to Canny.

Keywords: *ABC-ED, ABC Algorithm, Imaging, Edge Detection, Canny Edge Detector*

Introduction

In artificial vision and in image processing, edge detection deals with the localisation and identification of significant grey level variations in a digital image. Localisation relates to the search of points at a particular location in a grid of pixels. Identification relates to the process of deciding if a particular pixel belongs to an edge.

In image processing, an important number of edge detectors have been proposed exhibiting differences in terms of mathematic and algorithmic properties. In Ziou and Tabbone (1988) authors give an overview of research conducted in edge detection including properties of detectors, the methods for edge detection, the mutual influence between edge and detectors, and existing edge detectors and their implementation. One of the standard edge detection methods is proposed by Canny (1986), which offers an effective pixel identification by analysing every pixel in the image.

Artificial Bee Colony (ABC) algorithm, is a swarm intelligence algorithm that simulates the natural foraging behaviour of honey bees. Foraging behaviour of bees has a good balance between exploitation and exploration and uses communication mechanisms, such as the waggle dance, to explore and find new and better sources of food (Basturk and Karaboga 2006, Karaboga 2005). The term swarm is used to refer to any restrained collection of interacting individuals. A bee can discover different locations of sources of food. Different locations show different levels of nectar (better solutions). A bee chooses the location that holds the higher level of nectar. If a food source is exhausted during the foraging process, the exhausted source is

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abandoned, and bees explore new locations to find new sources of food (Cuevas et al. 2017).

ABC has been adapted for various problems in the area of image processing, in particular, in edge detection. A very interesting characteristic of ABC is that the probability of falling into local optimum is low, this is due to the combination of local and global search. In Benala et al. (2009), ABC was adapted for edge enhancement to improve visual perception of blurred images. Authors claim ABC algorithm is a powerful optimisation technique, they compare their results against results obtained using genetic algorithms techniques. In Parmaksizoglu and Alci (2011), the edge detection process is performed using cellular neural networks (CNN). More specifically, the ABC algorithm was used to design the cloning template of a CNN. This work claims that the ABC- CNN approach gave better results, when compared to the classical edge detection techniques. In Yigitbasi and Baykan (2013), ABC was used to develop a method for edge detection without mask operator to compute the fitness of a pixel. Grey level values were used as the knowledge of nectar. In Deng and Duan (2014), a hybrid model of saliency-based visual attention and ABC algorithm was developed to narrow the searching region of an image. Authors developed an unmanned combat air vehicle (UCAV) able to recognise targets in complex noisy environments. A recent work (Ahmad et al. 2017) shows how bees' algorithm can be applied to health care problem. Biomedical signals are low amplitude, and low frequency signals affected by different noises. Noise can be triggered by different sources such as power line interference, or movements of recording electrodes. Authors claim the noise ratio can be reduced by designing the proper digital filters, using the ABC algorithm.

In this work we combine an effective identification mechanism (Canny), with an efficient search mechanism, (ABC algorithm). We develop an efficient edge detector algorithm for digital images based on Artificial Bee Colony and Edge Detector (ABC-ED).

This paper is structured as follows: the first section is the present introduction. The second section, Literature Review, introduces fundamental concepts related to the ABC algorithm and the edge detection problem. The third section, Methodology, describes the design of the ABC-ED algorithm. The fourth section shows the results obtained followed by section five, showing the conclusions.

Literature Review

Edge detection is a technique used in many (artificial) vision approaches and applications. Edges detection allows for a significant reduction in the amount of data to be processed. This is accomplished by filtering undesirable or non-significant data, while keeping the most important structural properties of an image, improving thus the overall performance.

Edge detection locates and identifies important changes in the intensities of neighbour pixels. These changes characterise the boundaries among objects or regions in an image. Of course, many problems arise during the edge detections process. Just to mention a few, problems may arise from the inclusion of false positives (false edge detection) and false negatives (non-detection of true edges). Similarly, high computational processing time and noise are also among additional issues to be considered within edge detection process.

Different methods have been proposed for edges detection. These methods can - most of time - be grouped into two main categories: based on first order derivative and based on second order derivative.

Edge detection methods based on first order derivative (gradient methods), are very sensitive to noise and produce thicker edges. Second order derivative methods (Laplacian based), are methods concerned with an automatised edge detection (still very noise-sensitive).

Classic methods based on first order derivative are (Prewitt 1970, Roberts 1965, Sobel and Feldman 1968). In these methods there is a convolution among the image and their corresponding masks or kernels, to generate a gradient image where edges are detected through the search of minimum intensity values in the neighborhoods of pixels. The decision to classify a pixel as an edge depends on the value of a threshold μ. This is done for every pixel of the image.

The Laplacian is a 2-D isotropic measure of the second spatial derivative of an image. The Laplacian of an image highlights regions of rapid intensity change and is therefore often used for edge detection. The Laplacian is often applied to an image that has first been smoothed with something approximating a Gaussian smoothing filter in order to reduce its sensitivity to noise. The operator normally takes a single grey level image as input and produces another grey level image as output (Torre and Poggio 1986).

Canny is a very popular method that uses concept of both first and second order derivative. Canny edge detection is a multi-step algorithm that can detect edges along with noise reduction, because of the smoothing process of the image. Canny edge detector was developed in 1986 and is arguably the *de facto* standard edge detector. Canny satisfies the following properties: a) Low error rate: a good detection of existent edges only, b) good localisation: the difference between edge pixels detected and real edge pixels is minimum, and c) minimal response: only one detector response per edge.

In Canny, the first step is to smooth the image by using a Gaussian filter, then the gradient magnitude and direction are computed; the third step is for thinning edges through non-maximum suppression. Finally, a double thresholding process and edge tracking by hysteresis is applied.

In Thereshko (2000) the author modelled the food collection process of a honeybee colony as a collective action. The model considers three fundamental components: food source, employed bees and unemployed bees. It also restricts the collective behaviour to two different types: recruiting for a food source and the abandon of a depleted food source. In Karaboga (2005) the proposed ABC algorithm expands the model proposed in Thereshko (2000). More specifically, the model extends the categories to three groups: employed bees, onlooker bees, and scout bees - as it occurs nature.

In ABC algorithm, the food source represents a possible solution to an optimisation problem. The nectar of a food source corresponds to the quality (fitness) of a solution. The number of the employed bees or the onlooker bees is equal to the number of solutions in the population. At the first step, the ABC algorithm generates a randomly distributed initial population of *SN* solutions (food source positions), where *SN* denotes the size of employed bees and onlooker bees. After initialisation, the population of the positions (solutions) is subject to repeated cycles, $C = \{1, 2, ..., \text{Maximum Number of Cycles } (MCN)\}$, of the search processes of the employed bees, the onlooker bees and the scout bees. An employed bee produces a modification on the position (solution) in its memory depending on the local information (visual information) and tests the amount of nectar (fitness value) of the new source (new solution). If the nectar amount of the new one is higher than that of the previous one, the bee memorises the new position and forgets the old one. Otherwise she keeps the position of the previous one in her memory. After all employed bees complete the search process, they share the nectar information of the food sources and their position information with the onlooker bees. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount. As in the case of the employed bee, she produces a modification on the position in her memory and checks the nectar amount of the candidate source. If the nectar is higher than that of the previous one, the bee memorises the new position and forgets the old one Karaboga and Akay (2009).

Algorithm 1. *Pseudo-algorithm ABC. Main Steps*

Input: Parameters: *SN*, *MCN* and *limit*
Output: Food source with higher *fitness*

```
procedure ABC-ED( )
    INITIALIZATION( );
    cycle ← 0;
    while cycle < MCN do
        EMPLOYED-BEES-PHASE( );
        CALCULATE-PROBABILITIES( );
        ONLOOKER-BEES-PHASE( );
        SCOUT-BEES-PHASE( );
        MEMORISE FOOD SOURCE WITH HIGHER fitness( );
        cycle ← cycle + 1;
    end while
end procedure
```

The general structure of the algorithm is shown in Algorithm 1. *SN* is the number of food sources, *MCN* is the maximum number of cycles and *limit* is the number of tests to abandon a food source which cannot be improved. In every cycle of the algorithm *SN* food sources are considered.

Methodology

The input image *I* is represented by a matrix of *r* rows and *c* columns. Every element in the matrix corresponds to a pixel in *I*. The value of each element indicates the intensity of the pixel in a grey scale. More specifically, a value of 0 corresponds to a black pixel, a value of 255 corresponds to a white pixel, and the values within this range (i.e. 0 - 255) correspond to the black - white chromatic colour of the pixel.

In addition, a pixel also represents a possible source of food for bees. The fitness of a pixel ∇(x, y), is computed considering:

The intensity value of a pixel $I(x, y)$, in location (x, y). The gradient magnitude $G_x(x, y)$ in horizontal direction of $I(x, y)$. And the gradient magnitude $G_y(x, y)$ in vertical direction of $I(x, y)$ as described in (Canny 1986).

The components $G_x(x, y)$ and $G_y(x, y)$ are combined to obtain the fitness value of pixel (x, y), see Equation 3.1, fitness value of a pixel.

$$\nabla(x,y) = G(x,y) = \sqrt{Gx(x,y)^2 + Gy(x,y)^2} \qquad \text{(Equation 3.1)}$$

The quality of a food source is given by the difference of brightness intensities among a particular pixel and their neighbours. The greater the difference the higher the fitness (profitability of a food source).

The algorithm takes into account food sources with a *fitness* greater or equal than μ_{min}. In other words, a pixel is classified as a food source (edge) if its fitness is greater or equal to the threshold μ_{min}. This condition reduces considerably the number of pixels to be computed and therefore the overall execution time. Fitness computation of a pixel is performed once, at the moment of the food source creation.

The main steps of the ABC-ED are shown in Algorithm 2. The algorithm is a modified version of the original Canny procedure. More specifically, the proposed algorithm introduces a pixel selection mechanism based on bee colony. The localisation mechanism reduces the number of pixels to be processed in the original Canny procedure. Thus, reducing the total amount of edge thinning, double thresholding, and hysteresis performed.

The parameters of the algorithm are as follows. Input image matrix *IM*. Maximum μ_{max} and minimum μ_{min} thresholds parameters used by Canny. The initial population of food sources *SN* computed as $SN = \sqrt{r * c}$ [22]. An arbitrary number *MCN* representing the number of cycles associated to the search of food sources.

In addition, limit ∈ [0, 8] represents the maximum number of trials to explore the neighbourhood of a pixel. A value of eight indicates all neighbours have been analysed, see Moore (1969).

Finally, ε is a parameter ε ∈ [0, 100] used during the scout bees' phase to guide the search process of new food sources.

Algorithm 2. *Pseudo-algorithm ABC. Main Steps*

```
Input: Image and set parameters.
IM: input image (I) matrix.
μmin: minimum threshold value to classify a pixel as food source.
μmax: maximum threshold value to classify a food source as weak edge.
SN: amount of food sources.
MCN: maximum cycle number.
limit: maximum number of trials for exhausting a food source.
ε: value to control the search by exploration.
Output: OM: image binarised after hysteresis.
procedure ABC-ED( )
    IMAGE SMOOTHING( );
    INITIALISATION( );
    cycle ← 0;
    while cycle < MCN do
        EMPLOYED-BEES-PHASE( );
        CALCULATE-PROBABILITIES( );
        ONLOOKER-BEES-PHASE( );
        SCOUT-BEES-PHASE( );
        cycle ← cycle + 1;
    end while
    NON-MAXIMUM-SUPRESSION( );
    DOUBLE-THRESHOLD( );
    HYSTERESIS( );
end procedure
```

Four disjoint sets are defined to represent the possible states of a food source (i.e. a pixel). *AFS* represents the active food sources; every active food source is associated with one bee. *IFS* represents the inactive food sources; the sources in this category were replaced by a neighbour in the employed bees phase or in the onlooker bees phase. *EFS* represents the exhausted food sources for which all their neighbours have been examined. Finally, *RP* represents all the non-food sources. More specifically, food sources in this category have a gradient magnitude lower than μ_{min} (they will not be considered in future computations).

The output image is a binarised one. The image depicts the edges of the image in white, non-edge pixels are left in black.

In what follows, we provide a description for the different components of the Algorithm 2.

Edge detectors are affected by noise in the image. The noise must be filtered to prevent false edge detection. We apply a Gaussian filter to reduce the effect of noise on the edge detectors (Canny 1986). This process is known as smoothing.

In *Initialisation*, a population of *SN* food sources is created by random pixel selection. This process is accomplished by randomly selecting *SN* different (x, y) pairs which represent different locations in matrix *IM*. For every selected pixel, the corresponding fitness is computed. If the fitness value is equal or greater than μ_{min}, the pixel is a candidate to be a source food (i.e. an edge) and added to *AFS*. If the fitness value is less than μ_{min}, the pixel is added to *RP*.

In *Employed Bees Phase*, every employee bee *k*, $k \in \{1, 2, \ldots, SN\}$ is assigned to a food source $f_k \in AFS$. Only one employee bee is associated to a particular f_k. For each food source f_k in *AFS*, a candidate neighbour nf_k is randomly chosen. This random selection considers only those neighbours that remain unvisited. Once they are visited their fitness is computed.

If the computed fitness is less than $\mu_{\min}$, the pixel is added to *RP* and the value of $limit_k$ is increased in one unit. Otherwise, the computed fitness is assigned to nf_k; nf_k replaces the previous f_k food source, and the value of $limit_k$ is set to zero.

The selection of neighbours in the ABC-ED algorithm differs from the selection of neighbours in ABC algorithm. In ABC, the condition to replace the current food source, (f_k) is that the fitness value of nf_k is greater than the fitness value of f_k. In ABC-ED the condition to replace the current food source is that its neighbour nf_k has a *fitness* value greater or equal to μ_{min}. If the replacement occurs, f_k becomes inactive and added to *IFS*. If f_k does not have neighbours to visit, it is said to be exhausted and it is added to *EFS*.

Employed bees share their food source information with onlooker bees waiting in the hive. Onlooker bees choose their food sources depending on the acquired information. More specifically, onlooker bees choose a food source depending on the probability values calculated from the fitness values (provided by employed bees).

In *Calculate Probabilities*, for each food source f_k in *AFS* the algorithm proceeds as follows (according to the information supplied by the employed bees). The probability $p(f_k)$ of selecting a food source f_k is computed using expression shown in Equation 3.2, where $fit(f_k)$ represents the value for the fitness of food source f_k. This creates an *AVL* Roulette wheel selection (Baeck et al. 2000). Search of a food source is based on probability. A self-balancing binary search tree *AVL* (Adelson-Velskii and Landis 1962) represents the waggle dance of the employed bees. Equation 3.2 shows the probability of selecting a food source.

$$P(fk) = fit(fk) / \sum_{k=1}^{SN} fit(fk) \qquad \text{(Equation 3.2)}$$

In *onlooker Bees Phase*, *SN* food sources are chosen stochastically using the *AVL* Roulette. A food source can be chosen more than once in the same phase of the onlooker phase cycle. The greater the value of $p(f_k)$ and the greater the number of food source neighbours; the higher the probability an onlooker bee chooses f_k as a food source. Once the food source is chosen, the onlooker bees proceed like the employed bees' phase already described.

For each food source, it must be checked whether is exhausted. If the food source is exhausted, it is removed from *AFS* and then added to *EFS*, and the onlooker bee becomes scout bee. This new scout bee starts the search for new food sources.

In scout Bees Phase, the replacement is chosen between *New Random Exploration* and *Inactive Food Source* mechanisms. The *New Random Exploration* mechanism randomly creates a new food source (f_{new}) that is added to *AFS* and replaces the former f_k food source. The *Inactive Food Source* mechanism creates a new food source by removing the former source from the *IFS* set, replacing the former f_k food source, and adding f_{new} to *AFS*. A *FIFO* strategy is used to remove a food source from *IFS*. The reason behind this strategy is that early added sources possess higher probabilities of having neighbours not yet examined.

The parameter ε is used to guide the replacement mechanism. An ε = 100 indicates the replacement mechanism is *New Random Exploration. An* ε = 0 indicates the replacement mechanism is *Inactive Food Source*. Similarly values within ε ∈]0, 100[indicate the tendency of selecting *New Random Exploration* or *Inactive Food Source*. A value close to 0 is associated with a higher probability that the replacement mechanism is *Inactive Food Source*. A value close to 100 is associated with a higher probability that the replacement mechanism is *New Random Exploration*.

Once the bees' cycle is finished, a new *FSP* is created. *FSP* is the union of all the sets that contain a pixel (i.e. a candidate to be an edge) $FSP = AFS \cup IFS \cup EFS$.

The expected output is a binarised image obtained by applying non maximum suppression, double thresholding, and hysteresis to every pixel in *FSP*. Non maximum suppression is a technique used to thin an edge. After gradient calculation, an extracted edge can still be quite blurred. Non maximum suppression avoids the blurring by setting all the gradient values to 0 with the exception of the local maximal. Thus, a location with the sharpest change of intensity value is easily identifiable.

Double-thresholding is a process that determines how strong an edge is. The process considers two threshold values: μ_{max} and μ_{min}. These values are empirically determined and depend on the characteristics of the input image. A pixel with a fitness equal or greater than μ_{max} is marked as a strong edge pixel. A pixel with a fitness equal or greater than μ_{min} but lower than μ_{max} is marked as a weak edge pixel. The process of hysteresis analyses the impact of a strong pixel. More specifically, it analyses the neighbours of a strong pixel and it changes their states if they are weak pixels. This process is repeated for each new strong marked pixel. Only strong pixels are considered edge pixels [6].

For integrating the *ABC* algorithm with the Canny algorithm involved the following changes in *ABC*.

- A pixel is replaced when the fitness of the neighbour is higher than μmin. This is possible because the proposed algorithm is not searching for an optimum value, but for a set of solutions satisfying a given constraint.

- Four set were considered to represent particular states associated to a food source. a) *AFS* is associated to active sources (recruitment), b) *IFS* and *EFS* are associated to inactive and exhausted sources respectively, and c) *RP* associated to non-food source. These sets are used to avoid repeating computation of the fitness. These sets also help in the intensification of the search of edge pixels.
- In the stage of scout bees, the process of seeking for a new source introduces a parameter ε. This parameter is used to choose between two alternative searching processes: an exploratory search and an exploiting search. The exploratory search realises a random search on the solutions space.
- The exploiting search, re-visit pixels that have still non-explored neighbours. The result is an extensive and intensive search guided by the value of ε and the random value which, compared with ε allows to decide between intensive and extensive search.

Results

For testing, we used The Berkeley Segmentation Dataset and Benchmark (BSDS500) (Martin et al. 2001). The dataset contains 500 images. For each image, there are about five segmented images in grey scale. In addition, for every segmented image there is a ground truth image. The ground truth image contains the edges that correspond to an image. The dataset contains a total of 2696 segmented images. For every segmented image, threshold values μ_{min} and μ_{max} are computed in four different ways: Mean (Glasbey 1993), Median, MATLAB (given by the function *edge* using Canny on MATLAB), and Otsu (1979). In average, the computed threshold values are similar, except for MATLAB which produces significant lower values.

Computing the correct threshold values is critical. If the minimum threshold is too small, several pixels could be considered potential food sources, leading to an increment in the processing time. On the other hand, if the maximum threshold is too high, pixels that correspond to edges, may not be considered as such. In average, best results are obtained using Otsu.

Performance is measured as the percentage of pixels necessary to analyse, with respect to the total pixels of the image, to achieve the same results obtained by Canny. We use Hamming Distance (HD) (Hamming 1950), to get the difference between two binarised matrices. More specifically, we use *HD* to analyse the difference be- tween the image obtained from the ABC-ED algorithm, and the corresponding ground truth image.

Table 1 shows the results for different groups of images. The first three rows in the table consider an analysis of up to 25% of the total of pixels in the image. The fourth row considers an analysis that covers from 96% to 100% of the total amount of pixels in the image. A typical image has a size of 369 × 432 pixels.

Table 1 shows the output for the images. For simplicity images are grouped into *first group* (the first three rows in Table 1) and *second group* (the fourth row in Table 1). The first group contains 44.7% of the images in the database, while the second group contains 49.26% of the images in the database. The remaining 6% correspond to images related to analysis ranging from 26% to 95%. This correspond to less than 650 images and are not included in the overall analysis.

Table 1. *Summary of Output Results*

Quantity	PA	MCN	∆GT
3,224	15	82	1.03
1,079	20	122	1.54
518	25	131	1.79
5,312	100	151	2.01

In Table 1, *Quantity* refers to the number of output images. *PA* denotes the maximum percentage of pixels analysed. *MCN* represents the average number of cycles needed to detect the edges Canny detects. ∆GT corresponds to the average difference between the output image and its ground truth image.

The first row considers 3,224 output images (*Quantity*). For each image up to 15% of pixels are analysed (*PA*). In average, the algorithm executes 82 cycles for obtaining the output image (*MCN*). The average difference between the output image and the ground truth image is about 1% (∆GT). The same applies to rows 2, 3 and 4. It can be seen that the algorithm requires few pixels to analyse and cycles to compute to obtain an image that is no significantly different from the ground truth image.

Table 2. *The Best Results – Ground Truth Differences*

Image	Thresholding	PA (%)	∆GT (%)
1	Median	40.28	0.09
2	MATLAB	40.35	0.09
3	Mean	41.29	0.09
4	Otsu	47.77	0.09
5	MATLAB	40.02	0.1
6	Median	40.58	0.1
7	Mean	40.82	0.1
8	Otsu	50.27	0.1
9	Median	39.22	0.13
10	Mean	40.65	0.13

Table 2 shows our results. The results are ordered according to the average difference between the output image and the ground truth image (∆GT). The first row (lowest difference) shows that the output image presents a difference of 0.09% with respect to the ground truth image. The quantity of pixels analysed corresponds to 40.28% of the total amount of pixels of the image.

In all cases, the difference between the results obtained using the ABC-ED algorithm and the Canny algorithm is zero. Please note that both algorithms consider the same threshold values.

Table 3 shows the results (best outputs) when the criteria is to minimise the number of pixels to analyse (*PA*). The difference between the ABC-ED algorithm and Canny is zero (both cases consider the same threshold). In Table 3, the first row (less percentage of pixels to analyse) shows that the ABC-ED algorithm requires 10.24% of pixels analysed, and 57 execution cycles. The difference of the output image with respect to the ground truth image ∆GT is 0.78%.

Table 3. *The Best Results – Pixel Analysis*

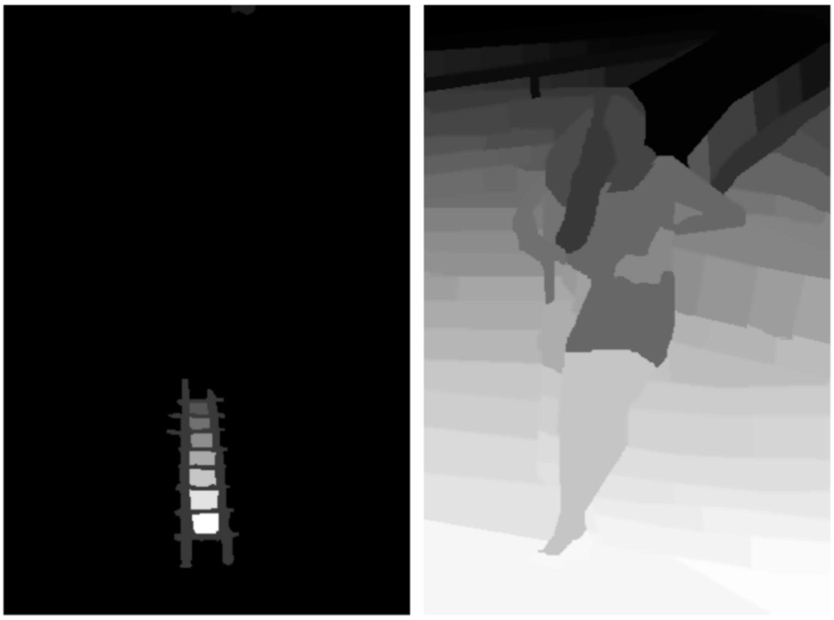
Image	Number of cycles	PA (%)	∆GT (%)
1	57	10.24	0.78
2	52	10.29	0.5
3	55	10.36	0.79
4	57	10.48	0.58
5	58	10.55	0.79
6	70	10.59	0.6
7	74	10.63	0.91
8	54	10.67	0.58
9	58	10.68	0.59
10	51	10.72	0.56

Figure 1 shows an example of two original images taken from the dataset used for testing.

Figure 1. *Example of Two Original Images*

Figure 2 shows one of the possible segmentations of the images shown in Figure 1.

Figure 2. *Example of Two Segmented Images*



(a) (b)

Figure 3 shows the corresponding ground truth of the segmented images in Figure 2.

Figure 3. *Example of two Ground Truth Images*

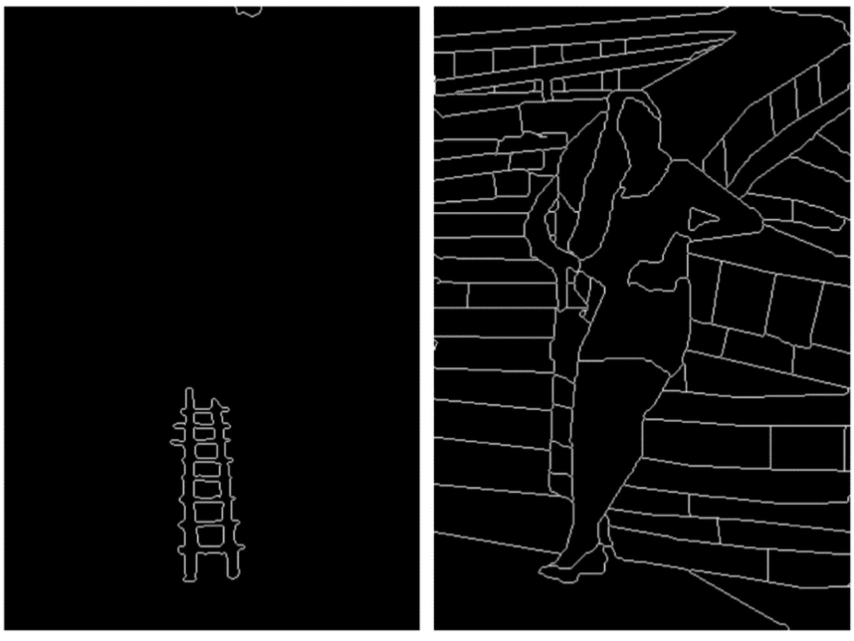
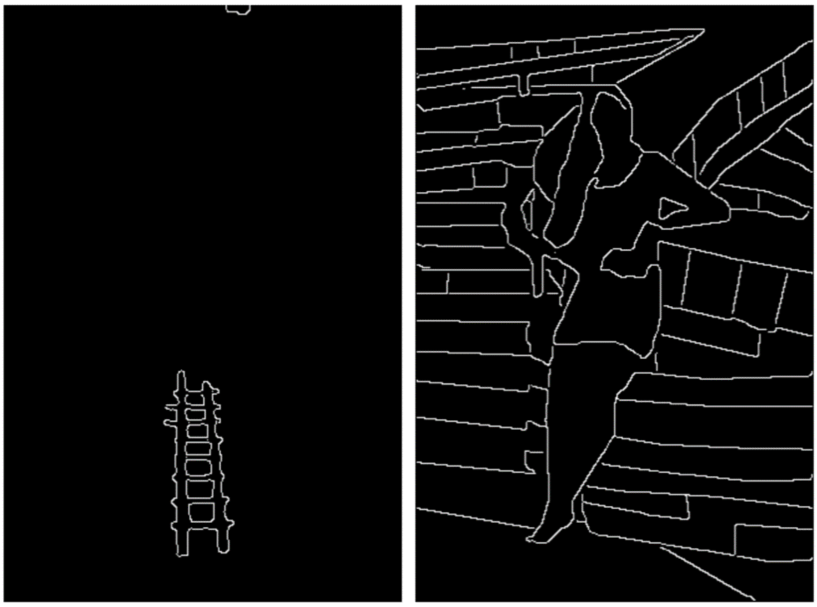


Figure 4 shows the output images obtained by applying the ABC-ED algorithm to the images of Figure 2. Please note there are small differences between Figure 3 and Figure 4.

Figure 4. *Example of Two Output Images*



(a) (b)

It is important to note that the input to the ABC-ED algorithm is a segmented image, (see Figure 2). This is because in the chosen database, the available ground truth images refer to segmented images (not to the original images).

Different images require different number of pixels to analyse. If edges are homogeneously distributed on the whole image, as in Figure 2b, the behaviour of the algorithm is similar to Canny performance. This is because the algorithm needs to analyse over 95% of pixels. The difference of the output image with respect to the ground truth image is close to 2%. Figure 2b belongs to the second group of images in Table 1. In the case of Figure 2b, the result is the output image using our approach, is shown in Figure 4b. If there are regions in an image with no edges, then the performance of the ABC-ED algorithm is improved.

Figure 2a belongs to the first group of images in Table 1. For this image, 10.29% of the pixels of the image are analysed. In the case of Figure 2a the result is the output image shown in Figure 4a. The difference with respect to the ground truth image is 0.5%.

Figure 5. *Original Image and Corresponding Output*

Figure 5 shows an example for a typical image *(Lenna)* and the resulting image using the ABC-DE algorithm. More specifically, the left side of shows the original image and right side, shows the result using the ABC-ED algorithm.

Similarly, Figure 6 shows another typical image example *(Cameraman)*. On the left the original image (*Cameraman)* and on the right the result using the ABC-ED algorithm.

Figure 6. *Original Image and Corresponding Output*

For the above images, the results are the same as the results obtained using the Canny algorithm, Otsu method (Otsu 1979). In the case of Figure 5, it is necessary to analyse 33.62% of the pixels. In the case of Figure 6, it is necessary to analyse 34.96% of the pixels.

Conclusions

This work integrates the ABC algorithm and the Canny algorithm. The result, the ABC-ED algorithm, reduces the number of pixels to analyse in an image, to detect its edges.

Results show that changes introduced to the ABC algorithm, and its combination with Canny algorithm, achieve the objectives proposed for this new algorithm: to detect every edge that Canny detects, avoiding analysing all pixels in the original image. Due to the fact that the algorithm integrates the Canny edge identification, it detects every edge that Canny algorithm detects.

The BSDS500 dataset was used in order to analyse the algorithm performance. The algorithm performs better when analysing images bounded to specific regions. Performance decreases for images with homogeneously distributed edges. The average value for PA is less than 60%, when all the images in the dataset are taken into account.

Additionally, experiments show that the number of pixels to analyse depends more on the image than the mechanism used to detect edges. The proposed algorithm obtains results that (in average) differ from ground truth values in no more than 2.01%.

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Stimulating Conscious Development Mechanism for Movement in Engineering Education

By Rosalie Van Baest[*]

The research is in line with a vision in our society that regards learning as a lifelong process that is not limited to education, it is an ongoing process in which a person is able to direct his own learning. Reflection and awareness are basic conditions in this process. The emphasis is on an intra-personal approach. The practical, exploratory and participatory research takes place in the context of Higher Engineering education which is often cognitive and practical oriented. Affective education is of significance in a process of conscious personal development. Self-reporting provides an insight into the subjective experience of students. The nature of exploratory research is that no strictly predetermined route can be followed by the researcher. Coming to conscious personal development is not a self-evident process. The following key question has therefore been formulated: "How" can one stimulate Higher Engineering students to open up for conscious intra-personal development?". The research resulted in the formulation of the S.C.D. model (Stimulating Conscious Development). (In Dutch: B.O.S. model). The S.C.D. model consists of two parts. The Preliminary research; a field experiment: the SCS module (Social and Communicative Skills), an experiential, student-centered lecture series. The objective of the SCS module is to stimulate Higher Engineering students to open up for conscious personal development. Gaining insight into interpersonal relationships is also of importance in the SCS module, related to effective teamwork. During the SCS process the Research terms were set down. They are the basic assumptions for the next part; a case study: a small-scale, in –depth study which includes three interviews, each time with ten Higher Engineering students, spread over a longer educational period. The case study focuses on the perspective of the research students, who participated voluntary and outside school hours in a positive way, in the research. Handling the method of approach of the S.C.D. model offers a possibility to stimulate Higher Engineering students to open up for personal development.

Keywords: *Conscious, Experiential, Intra-Personal Development, Openness, Reflection.*

Introduction

The context of the research is a practical didactic-pedagogical project in Higher Engineering education, that is in line with a vision in our society that regards learning as a lifelong process that is not limited to education, but is a continual process in which people are capable of directing their own learning (Zhao and Biesta 2012). Reflection and awareness are basic conditions in this process. The emphasis is on an intrapersonal approach. The importance of being open to personal development and consciously making personal choices

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is further underscored by societal developments that occur in increasingly rapid succession and the availability of an unprecedented volume of information.

In the 1990s, there was an urgent appeal from the business sector to the Higher Engineering and Technology education sector, to devote more attention to social and communicative skills in the curriculum, related to the development of personal qualities. Insight into one's personal qualities and those of others is valuable not just to a person's self, but is also a condition for effective teamwork and leadership. Working in groups becomes a focus area in the Engineering and Technology curriculum. At the same time, opportunities to encourage students to devote energy to develop self-knowledge are explored, the starting point of the research.

The quest for possibilities to encourage the personal development of Higher Engineering students, and to develop an insight into the perspective of students as a researcher, go hand in hand. The research can be viewed as a problem analysis that searches for the "knowing how" to create a possibility to stimulate Higher Engineering students in respect of their conscious personal development.

It is not always straightforward for (in this article Higher Engineering) students to motivate themselves in respect of their conscious personal development. The following key question was therefore formulated: are there possibilities to stimulate Higher Engineering students to consciously develop their personal qualities?

There are two underlying presuppositions.

1. People are interpretive beings, if possible, they attach significant meaning to their environment. They want to be recognised as subjects and not approached as objects. In the first place, this implies an intra-personal approach (Weick 1979).
2. People perform in a specific situation and are influenced by it. They get to know themselves through interaction with others within a specific context. This implies an interpersonal approach.

Focus on the intra-personal is essential for stimulating conscious personal development. In addition to the conscious development of self-knowledge, it is important to learn from interaction with others to thus expand one's self-knowledge. A quest for the path to internalisation is essential. The way in which this quest is shaped could then be of crucial importance.

Learning about one's personal style of learning offers a perspective on learning. Self-guided learning is essential in learning to learn and lifelong learning. The role of lecturers is of significance in the learning process of students.

Conceptual Framework

The practical research was started out and executed from a social constructivist perspective.

Everyone is constantly busy "making sense" of their environment. Enactment is the active process by which people view the world with an open mind and thus produce something new. Insight into the process followed is gained retrospectively (Weick 1979). To enable insight into the personal development of and for Mechanical Engineering students, the researcher tries to step into the shoes of the actors, as it were. This entails an intra-personal approach. The attitude and communication style of the researcher influences the attitude and communication of the students. From a social constructivist perspective, knowledge and insight are the result of communicative interaction between individuals.

Exploratory Research

The research process is a practical, exploratory and participatory process in Higher Engineering education. The nature of an exploratory research study means that the researcher can follow no strictly predetermined route.

The researcher's educational vision is strongly related to Kolb's experiential learning style, which focuses primarily on intra-personal development. According to Kolb, learning is the creation of knowledge through experience. It is not a linear process. Completing Kolb's learning cycle takes place at an abstract level: consciously reflecting on one's own learning at a meta-level. It is a holistic and cyclical learning process. The experiential-oriented lecturer has an essential role to play in Kolb's theory. (Kolb and Kolb 2005).

> "*When it is used in the simple, straightforward, and open way intended, The LSI usually provides valuable self-examination and discussion that recognizes the uniqueness, complexity, and variability in individual approaches to learning. The danger lies in the reification of learning styles into fixed traits, such that learning styles become stereotypes used to pigeonhole individuals and their behaviour*." (Kolb 1981-2005).

Methodological Framework

The practical research sought to identify the "knowing how": how is a possibility created to stimulate the conscious personal development of Engineering students? (Problem analysis).

The basic assumptions of the research are: working on the basis of an appreciative approach, the research takes place with those involved. The research is a means of learning, of looking for a connection between the content and the form of the research. The research adheres closely to the research practice and is directed towards change. It consists of two parts: a Field experiment (preliminary research) and a Case study.

In *Preliminary Research*, a Field experiment is carried out. The term refers to the method of data collection. The Field experiment describes and interprets the process side of a learning process in a Higher Engineering educational context: the development of the SCS module (Social and Communicative Skills) (In Dutch: SCV) in relation to the development of personal qualities. During the Field experiment, the researcher develops a certain insight into the perspective of Higher Engineering students on their personal development. The description of the SCS module is supplemented with quotes from Mechanical Engineering students (Van Baest 2016). SCS teachers also have a learning process during the development of the SCS module. The researcher gave experientially oriented SCS lectures to six lecturers to share practical experience of the SCS module. Explicit designation of the Research terms takes place in Part 1.

In the *Case study*, a small-scale, in-depth study is conducted in relation to the research terms. This part contains three individual interviews, each time with ten research students, spread over a longer period of time, to enable an insight into personal development within the context of their study programme**.** The three interviews are qualitative, semi-structured, in-depth interviews based on predetermined topic lists. The underlying question is always: what significance attach the research students themselves to their personal development during their studies?

The data for the practical research are generated in two ways:

- The development and design of the SCS module generates data that contributes to the "knowing how" of the practical research.
- Generate data via self-reporting in both parts offers an insight into the subjective experience for and of those involved. Some quotes of students are included in the article.

Practical Research

Preliminary Research: Module Social and Communicative Skills in Higher Engineering Education (SCS)

<u>Framework</u>

> "*The stimulation of new educational concepts better suited to our multidisciplinary society demands a dynamic setting that is difficult to predefine in literature. Which educational methodology is most appropriate for stimulating the desired learning process? How do people learn self-management? How do you facilitate reflection? Which learning processes ensure that people become more motivated? These learning processes involve behavioural change, personal development and emotions. Changing concepts and visions require more than just the ability to reproduce existing knowledge. These types of change processes are far more complex than traditional knowledge transfer*" (Shulman 2006).

The experiential SCS module is part of the foundation course of the Higher Engineering education programme (1998 to 2006). The introduction of the concept of teamwork to Higher Engineering education requires the commitment of Engineering students, in terms of developing teamwork skills. For this to happen, conscious reflection on personal attributes is important, in order to gain an insight into oneself, as well as an insight into the attributes of team members. The focus during the SCS module is on intra-personal development, teamwork skills also get attention.

Receptiveness to personal development is not straightforward in the context of Higher Engineering education. Therefore, an entirely different approach was chosen for the SCS module. An essential aspect of the approach to the SCS module comes forward by using experiential stimuli: Engineering students identify which emotions, related to a personal quality, they experience during the experiential SCS assignments (Kolb and Kolb 2005). The students cannot connect these stimuli directly to their Engineering studies. It offers the opportunity to step back from the usual elements of their technological studies.

The interaction between continually changing participants through the years in an educational context, creates different situations continually. The experientially oriented SCS module aims to give Engineering students the possibility to make independent choices in carrying out assignments that focus on the development of personal qualities in the environment in which they find themselves. Each SCS lecture focuses on a different theme that is related to a personal attribute. SCS themes include, amongst others: self-esteem, ambition, resilience to stress, capacity to motivate and to encourage, integrity, responsibility, creativity (Gramsbergen-Hoogland et al. 2005). During the SCS lecture students are exposed to an unexpected experience related to the relevant SCS theme of that lecture, so that the experience will better take root. It is meaningful for the students to be aware of the way in which their personal attributes get across to other students during the SCS lecture. It is also important to demonstrate a willingness to discuss and reflect on their personal attributes. What are the thoughts, emotions, ideas about their behaviour during the SCS lecture and how do they respond to feedback from fellow students?

The freedom to act autonomous as a student during SCS lectures is essential to stimulate Engineering students to take action on their personal development (Rogers 1979). They can make personal choices while carrying out SCS tasks and they can also make personal choices in terms of the approach to their reflective practice (Zhao and Biesta 2012). The SCS module offers the opportunity to engage in a cyclical learning process.

It is of great importance for the SCS lecturer to have a flexible mindset. The attitude and communicative style of the SCS lecturer forms part of the methodology of this research. The process of personal experience and development of SCS skills takes a number of years for the SCS lecturer.

During the period 1998-2006 the lecturer-researcher copied the reflections and evaluations of the SCS module of Mechanical Engineering students out of a positive approach (Seligman and Csikszentmihalyi 2000). This provides a basis for improving the SCS lectures. The reflections and evaluations identify which stimuli are effective and which are not, so changes can be made in SCS lectures in the future.

SCS Module in Practice in Higher Engineering Education

The SCS module is included in the foundation course of the Higher Engineering education programme thanks to a new vision for Engineering education. All SCS lecturers have a great deal of freedom in developing the new module.

- During SCS lectures, Engineering students are continually exposed to new experiences related to personal attributes. They reflect on these experiences through writing a reflective piece in order to expand their ability for self-reflection and to gain new insights into themselves (Giddens 1991).
- The SCS module is primarily focused on intra-personal development and the quest for internal reflection (Kolb and Kolb 2005). The module is focused on the affective development of Engineering students (Goleman 1999).
- Interpersonal skills are also of importance: sharing collective experiences to reflect on personal behaviour and attitude, and to learn from the behaviour and attitudes of fellow students.
- The shared SCS experiences are relevant to all team members, in the context of team building during project work. The SCS learning experience also offers the opportunity to get to know fellow students better on a personal level. In this respect, take part as a team in SCS lectures is essential.
- The continual recurring reflections in the reflective pieces of the students (Giddens 1991) connects the SCS lectures. That means that the SCS module offers the opportunity to engage in a cyclical learning process: after every lecture, students reflect on their learning experience and write a reflective piece of the lecture. At the end of the module, students reflect on the entire SCS module and summarise their thoughts, vision and ideas of the SCS lectures. They note what they regard as positive and negative points of the SCS module. Recurring themes in the reflections of the Mechanical Engineering students form a common thread that links the SCS lectures to one another. Substantiating ideas and opinions in the reflections is an important element during the SCS module. By writing a reflection after every lecture and an evaluation after every SCS period, students are encouraged to reflect consciously on their views of the SCS module and to substantiate these views (Bolin et al. 2005). Students are invited to engage actively in self-reflection (Masui and De Corte 2005).
- Each student participates in the SCS module from the perspective of his/her own personal background and is given the opportunity to follow his/her individual development path within a safe environment.

Student - I found it incredibly useful to complete this workbook. It is a good way of reflecting on how people are communicative and social beings in practice. Besides, it is fun to work on it in class, knowing that there is a purpose behind it.
Student - I found PCS really helpful to do, particularly writing pieces in the workbook. What you learn in the lectures through tasks, is reflected in the workbook. It makes you reflect more deeply on certain things. (PCS is another name for SCS).
Student - It was actually good to write all those pieces in the workbook. It made me see the world in a different way.

The ability to reflect consciously, to take a step back and think about an experience consciously, is essential for the learning process of development of self-awareness: gaining an insight into oneself, an insight into personal strengths and weaknesses that emerge from behaviour and attitude demonstrated in the SCS lecture (Denton 2011).

Student - In my opinion, SCS is not like traditional learning. They enable you to reflect on things on which you normally would not. This increases your self-awareness. And this self-awareness may, for example, enable you to behave differently in certain situations.
Student - By having to write a page every week about subjects related to communication, you are forced to look at yourself. You become more aware about what you think about certain things and how you perceive things. I enjoyed the lectures and that had a positive effect on the learning process.

During the SCS module it is not the intention to teach students a number of tricks, but to encourage them to reflect, to make them aware of their social and communicative skills in relation to their personal attributes. SCS is about stimulating developing self-awareness, reflecting on individual roles, and acquiring experience and knowledge about the personal attributes of fellow students within the context of SCS. Self-awareness and an insight into personal attributes are not achieved without effort.

It is important, for students as well as for the SCS lecturer, to gain collective experience during the SCS lecture to get insight in different approaches of the SCS assignments. The issue is always whether the stimuli offered, are motivating enough to adopt a personal approach in completing the assignments. The element of surprise is relevant in SCS lectures. A number of assignments were included in the SCS module for a long time.

For example the collective completion of Kolb's learning style test provides a collective learning experience during the SCS lecture. Students discover and identify their personal learning styles. Collectively completing and developing the learning style test makes it possible to gain a sense of the personal learning style, an intra-personal process, and to get to know the learning styles of fellow students, interpersonal (Kyprianidou et al. 2012).

Feedback on the interpretation of the learning style test by the SCS lecturer is crucial. If the learning style test is only completed once during the study programme, no internalisation of one's personal learning style takes place (Kolb and Kolb 2005).

The SCS lecture series progresses well if Engineering students are receptive to the methodology of the SCS module. This means: students have a flexible attitude and engage actively in SCS lectures. They subsequently carry out a reflection exercise according to their own insights, which they write down in a reflective piece in their workbook. Some students find it very difficult to get used to this style of teaching and reflection: they require more time and space. In addition to receptiveness for their own insights, the students develop receptiveness for their fellow students. The shared learning experience provided by SCS lectures and the insights that are developed as a result, may provide a positive contribution to an enjoyable teamwork experience during the projects.

The book "Personal Quality" (Gramsbergen-Hoogland et al. 2005) offers theoretical support for subjects related to the SCS module.

Self-reporting in the SCS part of the research provides an insight into the subjective experience of Engineering students. A number of terms (Research terms) are highlighted implicitly in the students' reflections and evaluations. The concept of "independence" does not come to the fore in the students' reflections. However, independent (autonomous) functioning is essential and a starting point in SCS lectures. The SCS lecturer stimulates autonomous behaviour and choices from the students (Sousa et al. 2012).

Subjects related to the Research terms which come to the fore in the students' reflections and evaluations (self-reporting) are: contemplation (related to reflection), self-knowledge, motivation (Ryan and Deci 2000) and humour:

> *Student - In a fun way, you discover, indeed you suddenly realise, what is important in our society. That is the fun part, you suddenly acquire that knowledge, which is not theoretical, but has to be transferred.*
> *Student - I hope that more similar subjects will be offered over the coming years, of which we learn in an enjoyable way and we are not always dealing with material that needs to be processed, but with other things too.*
> *Student - With the greatest of ease, we learn to communicate well, which I think is a really good approach".*

and development:

> *Student - I think that in future, everyone will benefit from the SCS lectures we received. You learn to reflect on your actions, which is always good for personal development.*
> *Student - Usually, you do those things unconsciously, but the SCS lectures teach you awareness. Once you are aware, you are sometimes able to respond better to certain situations".*

In addition to experience and theoretical knowledge of SCS themes, a focus on the personal development of young people and a good atmosphere (Seligman and Csikszentmihalyi 2000) during the SCS lectures is especially important for the SCS lecturer. The role and attitude of the lecturer during the SCS lectures is crucial for the progression of the SCS lectures. Stimulate to open up for conscious personal development is the essence of the SCS module.

Research Terms

"Knowing about" does not automatically lead to "knowing how", certainly not when it comes to stimulating personal development. During the SCS process the Research terms were set down. The Research terms consist of: Keywords and Core Values. The "knowing how" of the Keywords and Core Values are connected to one another.

- The Keywords are: self-knowledge, autonomy (Swaine 2012), wellbeing (Seligman and Csikszentmihalyi 2000, Vergeer 2001) and intrinsic motivation (Ryan and Deci. 2000) in relation to personal development.
- The Core Values are: security and trust, space and time, flexibility, simplicity, humour and learning through play. They are expressed in the attitude and communication style of the SCV lecturer.

In the scope of this research a great deal of research is conducted around the "knowing about" of the Keywords and far less around the "knowing how" of the Keywords. Little research was conducted around the "knowing about" and "knowing how" of the Core Values. The Keywords are related to one another and are connected to the process of personal learning and development that takes place during (Higher Engineering and Technology) education. The set down of the Core Values is supported by the reflections and evaluations of the Engineering students during the SCS module. The Core Values are developed from an intra-personal perspective by the lecturer-researcher. They form the basis upon which the SCS lecturer shapes the SCS lectures in his own way.

Consciously choosing a method of communication contributes to the progression of communication in an educational context. The following characteristics of dialogue can be recognised in the SCS module: equality, mutual trust, mutual respect, mutual openness and mutual understanding (Smaling 2008). Consciously applying a specific method of communication does not happen automatically. The objective of an appreciative attitude and the establishment of an equal dialogue with students is to give students as much freedom as possible to make their own decisions and to stimulate them in terms of personal development within the context of SCS. The way in which a SCS lecturer gives feedback has an influence on the lectures.

Case Study

During the learning process of the lecturer-researcher in the preliminary research, the Field experiment, a need for a deeper insight into the intrinsic motivation and personal development of Engineering students originated (Sousa et al. 2012). The idea came into being that stimulating the conscious personal development of students during their Engineering studies requires more time and space, than given to the SCS module in the curriculum, to make individual students aware of the growth and development of their personal qualities.

The Case study focuses on the perspective of ten research students, who participated voluntary and outside school hours in the research. This offers the opportunity to generate data about the subjective experience of ten Mechanical Engineering students in relation to their studies during the research period. The Keywords form recurring discussion points during the individual interviews. The Core Values guide the researcher's communication and attitude.

In the Case study three individual interviews, with each research student, were carried out during a longer period of education. A number of personal stories are important for gaining a deeper understanding of personal development and they offer an opportunity for the research students to internalise aspects of their personal development.

The Core Values provide a basis for the communication and the attitude of the researcher during the interviews. The atmosphere during the interviews determines the progression of the interviews. In addition to the characteristics of dialogue, the characteristics of critical dialogue: argumentative character, reflective character, evaluative character, cooperative character and mutual favourable interpretation (Smaling 2008) are applied and stimulated.

During the interviews the research students were given the freedom and time to express their own individual values and stories: their narratives (Basten 2010). By communicating their personal values and stories in relation to the Keywords, the research students can get to know their personal reality, related to their study, in a conscious way (Zhao and Biesta 2012). Repetition makes internalisation of one's self-image possible.

Before the interviews takes place topic lists were composed. They provide a framework for the interviews, but also allow scope for personal stories. In addition to discussing the Keywords, each interview also covers "other" topics to promote the playful character of the interviews and to encourage openness and spontaneous responses from the students, for example the pop-up book "*Journal des inventions de Leonard da Vinci"* (Da Vinci 2008).

The interviews demonstrate the research students' openness to self-knowledge and the importance they attach to acquire and develop self-knowledge.

Each research student demonstrates his own paradigm, his own subjective perspective (Barker 1996). Conscious reflection plays an essential role in the process of conscious development.

At the end of the third interview each of the ten research students gave his opinion about the experience with the research (self-reporting). Every research student has a pseudonym to protect their privacy.

> ***Beethoven.*** *"I think it also gives a good look of who you are yourself. By thinking about the questions you asked. Yes, I do think indeed that it is for yourself ... ".*
>
> ***Jesse****. "It was not obligatory. It was completely without obligations. I liked to do it, everything that is written on paper was said. It was always funny to read it back at home. To see yourself a bit on paper. Yes, very funny. I also let my parents read it sometimes and they really had something like: "yes, that fits exactly with you".*
> *"Yes, self-awareness, a little bit. When it is on paper and you read it again sometime, then indeed you have something like: "I have to pay more attention to that, or something like that".*
>
> ***Homer****. "It was good. But so those interviews are just right. You can chat a bit. Of course you will think about it for a moment ... Because you bring forward some subjects that you obviously do not speak out by yourself. But really thinking profoundly about it? No, I did not do that. But there are things that you become more aware of".*
>
> ***Dylan.*** *"In itself as pleasant. I especially liked it because where you worry about, what you think, you can express that. I think that's nice about the research. For me personally, I liked it. Maybe a little less as reflection, because I was working on it myself. If I can ever help you or something, then I'd like to hear it. I mean that too. Perhaps my role as a thinker, if you ever want to brainstorm about something, maybe".*
>
> ***Lou.*** *"I learned a lot of it too. Handy to look back on certain things and also to think about it in a different way. Then I think I have benefited from it myself. I don't know what the results are going to be, but ... I first had the idea that my motivation would not change so much in the course of my education. But still you're going in another direction. It has not changed dramatically, but nevertheless it steered towards what I want to do". "There's a lot of change, I did not expect that. When I think back, if I had not participated in that research, then I also would not have thought about that it is changed. Of course about making decisions, but not about that motivation: "What do I want to do?" .*
> *"Motivation and looking back at what you have learned and what kind of developments you have gone through ... Technical students, they don't do that much. If you think about it as the group, then it is: "no, we don't do that, we build stuff ".*
> ***Raven.*** *"Positive. I have also learned a few things myself. You reflect indeed. You say it instead of thinking about it. You can also place yourself, I know what my direction will be ".*

Thor. *"Yes, nice, yes. I could help you with it, I think, or not with that research? For myself I have learned a number of things, especially those learning styles and such, I did not know that at first. I did not know those four learning styles. I have something there, also maybe in the future. I gained more knowledge and learned more about myself. So. Yes, that was fun and significant".*

Casper. *"I liked it. It's very funny, because if you read those interviews again, you realize more how you're put together. And I thought that was really funny. And very interesting. It is a bit awareness. Through such questions and also if you, say you walk out the room after a short while, then it's always ... Then I'm still working on it some time. And actually I think that this is just ... If you could do that for everyone here... Yes, it takes a lot of time, of course ... But it's okay, so to speak. Just simply good about you ... To be able to speak about how you think you are. And what your motivations are. Because it's just very nice to be able to talk to someone about ... ".*

Django. *"Well, I liked to tell a story. I think that at the end of the research I have to put everything together. Then you can see the process a little bit, because that is rather difficult per interview. It is a process and a lot has changed. When it is finished, I want to look at it again and put it one after another ".*

Sky. *"It was fun. There was always interest in what you like and everything. Those qualities and how you experience it here at school. That was nice and the sandwiches of course ".*
"I think a bit more about how you stand in live, how you look at yourself. That's what it's about for a great deal. That you think more about it. The piece of text of a few moments ago "Passion and intuition" (Goleman, 1999) that stays with me. That it's going that way for myself, also in business."

After recording and analysing the interviews (the final version of the interviews is approved by the research students), the narrative of each research student is told in a new way by the researcher. The items “Self-knowledge”, “Learning style” and “Personal development” of each interview, amongst others, feature in the new idea. The voice of the narrator is part of a greater community, in this case Higher Engineering education. That voice is represented by the narratives of the research students.

Review

The practical research ultimately resulted in the formulation of the S.C.D. model: the Stimulating Conscious Development model (In Dutch: B.O.S. model). The S.C.D. model consists of two parts.

The first focuses on openness and stimulating the personal development of (Mechanical Engineering) students.

The second comprises three interviews, in each case with ten research students, spread over a longer period of education to facilitate internalisation of the Keywords. The interviews focus on the individual, personal development of students in an educational context.

Use of the approach of the S.C.D. model offers a possibility to stimulate Mechanical Engineering students to be open to personal development. The methodology applied offers guidelines for a potential strategy within an educational framework and calls for further research.

To develop an insight into the subjects: intra-personal development, reflection, Kolb's learning style, self-knowledge, autonomy, motivation, individual interviews and the learning process of personal development, was of critical importance for the research and contributed to the explicit definition of the research terms.

Conclusions

Conclusions related to the methodology of the S.C.D. model applied in Higher Engineering education:

- In the curriculum of Higher Engineering education a process of conscious personal development of students has to be given time and space from the start of the first year of an academic study.
- The S.C.D. model (affective education) is embedded in the curriculum of Higher Engineering education and is related to some of the other (technical or practical) modules.
- The emphasis on stimulating the process of conscious personal development of students lies in the first year of study.
- Experiential learning in the SCS module, that is related with the process of intra-personal and interpersonal learning, is introduced in the curriculum at the start of the first year of an academic study. Students can experience the personal qualities of themselves and of their fellow students, which can support teamwork in engineering projects. Communication about the experiences with all the participants and feedback on the experiences is essential.
- Introduction of a reflection notebook to write down the SCS reflections and evaluations: a way to keep the reflections and evaluations together. This gives the opportunity for each student to read the reflections and evaluations again and notice possible changes in their personal development and their way of thinking.
- Continually stimulating openness to personal development makes internalisation of self-knowledge possible.
- The role of the SCS lecturer is of the greatest importance in the S.C.D. model. Therefore the lecturer must have the opportunity to experience a SCS learning process himself (or herself) to gain insight

into the conscious personal learning process of him/herself, as well as of the students in Higher Engineering education.

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